REPORT ON

COMBUSTION TESTING PROGRAM

AT THE

SWARU PLANT, HAMILTON - WENTWORTH

for

ONTARIO MINISTRY OF THE ENVIRONMENT

AIR RESOURCES BRANCH

ARB - 43-84-ETRD

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by

ENVIROCON LIMITED
MISSISSAUGA, ONTARIO

in conjunction with

W.J. Howell Engineering Ltd.

January 1984

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Mississauga Office

January 6, 1984.

Mr. E.T. Barrow,
Project Officer,
Ontario Ministry of the Environment,
880 Bay Street,
Toronto, Ontario.

Reference: 73.19G.15

Dear Mr. Barrow:

It is a pleasure to forward our final 'Report of Combustion Testing Program at the SWARU Plant, Hamilton-Wentworth'.

We appreciate the opportunity of participating in this particularly interesting and relevant program, which we feel marks an important milestone in the topical area of dioxin and furan emissions from combustion sources. The Ontario Ministry of the Environment deserves considerable credit for their support and committment to this project, since it is of benefit in terms of both the direct environmental impact of the SWARU plant and, in a broader sense, by increasing the body of available information on the presence, generation, and fate of halogenated polynuclear aromatic chemicals.

We also appreciate the assistance of the Process and Combustion Review Committee for their particpation and assistance through the project, and in particular wish to thank the participants from Tricil Limited for their extensive involvement in helping to achieve the project objectives.

Yours truly,

ENVIROCON LTD.

P.G. Complin,
Project Manager.

PGC:s

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1.0 INTRODUCTION

The Solid Waste Reduction Unit (SWARU) plant receives municipal solid waste from the Municipality of Hamilton-Wentworth. The refuse is pulverized to generate a refuse derived fuel which is burned in a steam plant consisting of two travelling grate boilers rated at 13.4 kg/s (105,700 lbs/h) saturated steam at 1720 kpa (250 psig). The plant was installed by the City of Hamilton, and is presently owned by the Regional Municipality of Hamilton-Wentworth. The plant is operated by Tricil Limited under contract with the Municipality.

In February 1983, the Ontario Ministry of the Environment formed a Liaison Committee and four technical committees to address the issue of dioxin emissions from the SWARU plant. The Process and Combustion Review Committee developed terms of reference for a combustion testing program. In mid-March 1983, Envirocon Eastern Ltd. were retained by the Ministry of the Environment to carry out the program.

2.0 PROGRAM DESCRIPTION

2.1 Objectives

The specific objectives of the testing program were:

1. To review equipment and operating procedures.
2. To investigate how operating parameters affect combustion.
3. To determine performance under a limited set of operating parameters and identify desirable operating parameters.
4. To select and monitor operating conditions concurrent with obtaining a series of samples for dioxin and other analyses by others.
5. To analyze and report all of the above and provide relevant comments.

It should be noted that the tests under item 4 above were considered diagnostic in nature. Their primary function was to identify potential operating conditions for full scale definitive stack tests to achieve accurate dioxin emission results.

A further objective of the program was to complete the test work in the shortest possible time frame.

To meet the stated objectives, field tasks were identified as follows:

* Pretest Program
* Cold Flow Study
* Combustion Runs
* Diagnostic Tests

Details of the above are given in the following sections. All of the above were carried out on the boiler known as Number 1. For the combustion runs and diagnostic tests, boiler Number 2 was not operated during the testing periods.

2.2 Pre-Test Program

Pre-test surveys were conducted during March 1983 and included the following:

1. Observations of the operation of the fuel preparation system, boiler and auxiliaries.

2. Review and discussion of drawings and performance specifications of the unit and auxiliaries.

3. Specifications for the installation of additional sampling facilities.

4. Internal Inspection of the test unit, including:
   - condition of grates and seals
   - condition of control dampers
   - cleanliness of heat absorption surfaces
   - cleanliness of ducts and flues

5. Discussion of potential test matrices with the Project Officer and the Process and Combustion Review Committee.

In addition, necessary consumables were procured, test equipment was calibrated, flue gas test manifolds were constructed and equipment and supplies were transported to the site.

2.3 Cold Flow Tests

Cold flow tests were undertaken in early April 1983 to obtain information on flow patterns and on the interaction of undergrate and overfire air flows.

Under cold boiler conditions without fuel, both undergrate and overfire air were supplied to the boiler in varying quantities and under various control settings. Flow velocities were measured at a series of locations inside the furnace above the grates. Smoke bombs and paper ribbons were used to supplement the velocity measurements.

2.4 Combustion Runs

The objective of the combustion runs was to measure boiler parameters under different operating conditions and assess the performance of the unit. The main parameters that were varied are:

1. boiler load
2. undergrate air flow
3. overfire air flow

During the combustion runs, measurements and sampling were conducted and are reported in Appendix I.

The calendar shown in Figure I shows the dates for the combustion runs.

2.5 Diagnostic Tests

The diagnostic tests were performed to monitor operating conditions concurrent with dioxin, furan, and precursor sampling by others.

The results of the combustion tests were used to select conditions for the diagnostic tests.

Figure-1: CALENDAR OF RUNS AND TESTS

April 1983

SUN	MON	TUE	WED	THUR	FRI	SAT
					1	2
3	4	5	6	7	8	9
10	11	12 Combustion Runs	13 Combustion Runs	14 Combustion Runs	15 Combustion Runs	16
17	18 Combustion Runs	19 Combustion Runs	20 Combustion Runs	21 Combustion Runs	22	23
24	25 Combustion Runs	26 Combustion Runs	27 Combustion Runs	28 Aborted Diagnostic Test	29 Aborted Diagnostic Test Combustion Runs	30

May 1983

SUN	MON	TUE	WED	THUR	FRI	SAT
1	2 Combustion Runs	3 Combustion Runs	4 Diagnostic Test	5 Diagnostic Test	6 Diagnostic Test	7
8	9	10 Diagnostic Test	11 Diagnostic Test	12 Diagnostic Test	13 Diagnostic Test	14
15	16	17 Diagnostic Test	18	19 Diagnostic Test	20	21
22	23	24 Diagnostic Test	25 Diagnostic Test	26 Diagnostic Test	27 Aborted Diagnostic Test	28
29	30	31				

Twelve dioxin tests were completed, and a thirteenth test, consisting of 2 out of the 3 traverses for dioxin/furan and precursors was accepted as sufficiently long to justify laboratory analysis. These tests were performed over 16 test days as shown in Figure 1.

The major samples taken and parameters measured during the diagnostic tests were as shown in Table 1. Results of the diagnostic tests are tabulated in Appendix II.

TABLE I

SUMMARY OF SAMPLES TAKEN AND PARAMETERS MEASURED

PHYSICAL SAMPLES COLLECTED

- Boiler Fuel
- Grate and Precipitator Ash
- Flue Gas Particulate
- Flue Gas Moisture
- Flue Gas Velocity

DATA COLLECTED

- Control Room Instrument Readings
- Grate Temperature
- Furnace Temperature at Two Levels
- Furnace Top Temperature
- Sampling Manifold Temperature

VOLUMETRIC FLOWS MONITORED

- Undergrate Air
- Overfire Air
- Feed Chute Induced Air
- Flue Gas

GASES CONTINUOUSLY MONITORED

- Oxygen (O_2)
- Carbon Dioxide (CO_2)
- Carbon Monoxide (CO)
- Total Hydrocarbons (THC)

3.0 PROCESS DESCRIPTION

The SWARU facility receives and processes municipal refuse to form a refuse derived fuel for subsequent use in the steam plant boilers. For convenience, the process has been sub-divided into the following categories:

- Refuse Preparation and Handling
- Conveyors and Boiler Feed
- Furnace and Boiler Bank
- Combustion Air
- Flue Gas
- Ash Removal

3.1 Refuse Preparation and Handling

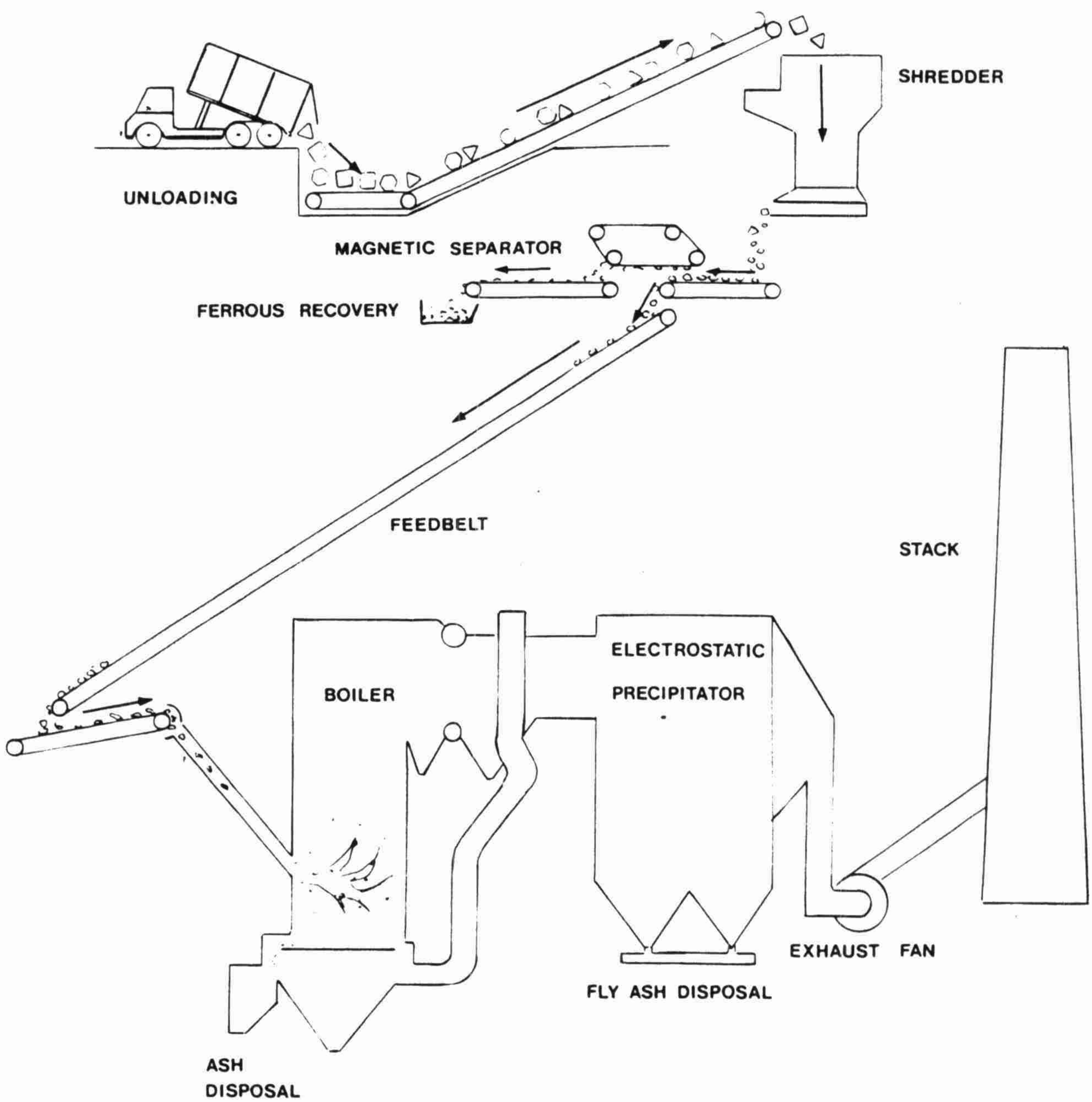
Figure 2 is a schematic representation of the process including fuel preparation and handling.

The system consists of storage, feed to pulverizers, and a series of constant speed conveyors which deliver the fuel to the boilers. It takes approximately 2.5 minutes for fuel entering the pulverizers to be delivered to the boiler feed chutes.

The normal practice is for the trucks to dump their load onto the tipping floor. A front end loader piles the refuse, and pushes it into the pit as required. The pit is 12.2 m (40 ft) wide, 30.5 m (100 ft) long and 9.1 m (30 ft) deep. Four conveyors transport the refuse from the pit to the pulverizers. The conveyors run horizontally along the bottom of the pit, onto which the refuse is dropped. From the bottom of the pit the conveyors run sharply upwards to the pulverizers.

FIGURE 2

Process Schematic



The speed control for each conveyor can be adjusted manually or controlled automatically from the boiler room. The set point for the automatic control is the furnace top temperature which is selected by the operator.

Current operating policy calls for gradual introduction of refuse to the pit by front end loader or direct truck transfer to hold a body of refuse in the area of the incline only.

The conveyors are equipped with angle iron flights mounted at right angles to the flow direction. These flights cover about a third of the belt from edge to center, and are staggered side to side about 0.9 m (3 feet) apart. There are also some knife-edged flights mounted parallel to the direction of conveyor travel.

Immediately above the conveyor direction change is a bridge at the tipping floor level. This bridge is continuously manned by labourers who use long handled rakes to remove large objects (particularly metals) that may adversely affect the pulverizers and to level the refuse on the inclined conveyor section to provide regular feeding to the pulverizers.

Each of the 4 vertical pulverizers consists of a vertical drive shaft with radially mounted hammers. The pulverizers are top loaded by the feed conveyors.

The number of hammers and hammer material have been changed from the original design and the pulverized material falls radially from the bottom.

Wear and tear on the mild steel hammers requires a daily hammer inspection.

3.2 Conveyors and Boiler Feed

The fuel transfers from the pulverizer to a belt Conveyor (No. 5) Ballistic plates have been installed, to direct the fuel, and to absorb shocks from heavy pieces.

The fuel passes beneath a magnetic separating conveyor which removes ferrous materials. The metals are dropped onto the upper of two conveyors (No. 5A) which carries the metals to storage. After the metal separator the fuel drops onto the lower belt, (No. 6A) and is carried outside the building for transfer to conveyor No. 6B and a second magnetic separator. The fuel is then transferred to conveyor No. 7, which in turn brings it into the boiler building. The transfer points from conveyor No. 6B to No. 7 and from No. 5 to No. 5A and No. 6A are both monitored in the control room by T.V. cameras.

Conveyor No. 7 discharges into a chute with a diverter that splits the stream of fuel between the two boilers. The fuel then travels on a final horizontal conveyor through a swinging chute and bridge breakers to the feed chutes.

At the furnace there are two dampered, full width, air slots to pneumatically convey the refuse and spread it onto the grate. The air supply for these slots is provided by the overfire air fan, via a dampered plenum and individual dampers for each slot.

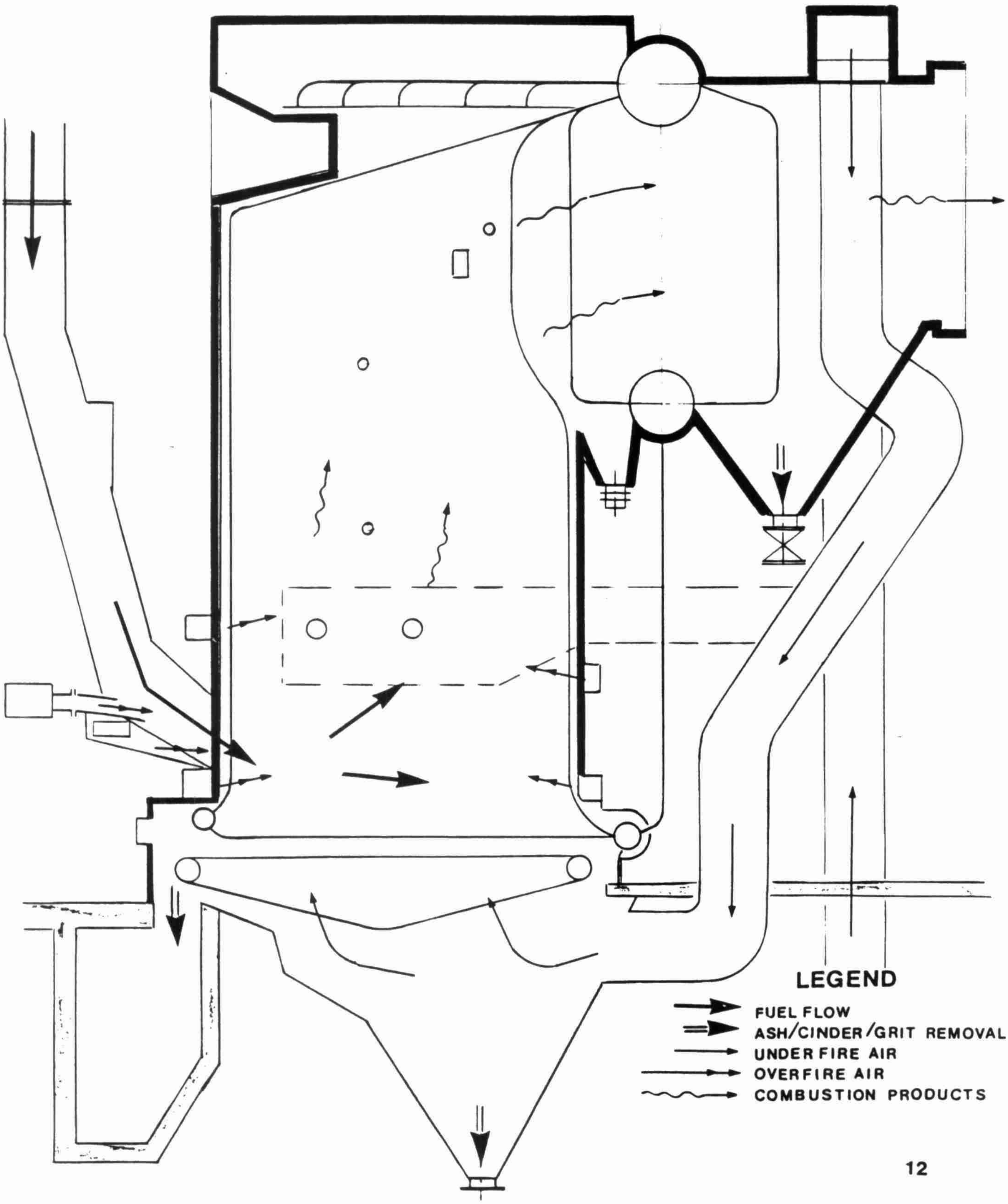
3.3 Furnace

The furnace and boiler bank are illustrated on Figure 3.

The furnace is 4.1 m (13.5 ft.) wide and 4.8 m (15 ft. 8 1/2 in) deep. Membrane water walls extend from just above the grate to the furnace roof.

FIGURE 3

Boiler Cross Section



Each of the three feed chute inlets are 35.6 x 55.9 cm (14 x 22 inches). The centreline of the inlet is 2 m (6 feet 6 inches) above the grate.

A three section travelling grate moves from the rear to the front and discharges the ash into a wet ash hopper below. The grate bars are provided with holes for undergrate air distribution.

The original grate seals at the back of the furnace were removed and replaced by a revised design, and are intended to rest on the grate. Front seals are provided below the grate.

The undergrate air compartment is located directly below the grates and also serves as the grit bunker. A screw conveyor transfers grit to below the water surface level in the ash pit.

The overfire air system in the Boiler consists of two plenums with nozzles located along the rear wall (upper and lower), a plenum with nozzles on the front wall below the feed chutes, and a plenum with slots in the vertical tube membrane walls above the feed chutes.

Two natural gas fired burners, used primarily for start-up, are located in the left wall above the feed chute level.

The flue gases pass through the boiler bank and over the tubes of the air preheater. The steam is used to run a steam-turbine generator and/or is consumed in a steam condenser.

The hopper below the front boiler bank has been closed off. The rear boiler bank has a screw conveyor followed by a gravity discharge. Originally cinder collected from the rear boiler bank was injected into the furnace, but now they are conveyed directly to the wet ash pit via a horizontal screw conveyor located several feet above the water level in the pit. The unit is equipped with both wall and boiler bank soot blowers.

3.4 Combustion Air

The furnace is supplied with separate undergrate (UG) and overfire (OF) air.

The UG supply is furnished by a forced draft (FD) fan located in the basement. Ambient air passes through variable-vane inlet dampers and is discharged vertically to the air preheater where it passes through the preheater tubes, and through a return duct to the undergrate air compartment. Overall flow control is by a damper inlet on the inlet to the undergrate air compartment. There is no flow control between grates or sections within the air compartment. The FD fan is operated to maintain a constant duct pressure.

The OF air supply originates at the upper level of the boiler building, and proceeds via an inlet duct to two fans arranged in parallel on the ground level outside the boiler building. Discharge from FD fans is ducted into the original OF air header. This header is interconnected with the system supplying boiler #2 with isolation by butterfly dampers. The OF air system supplies the four overfire air plenums and the feed chute plenum.

3.5 Flue Gas

The combustion gases, after leaving the air preheater, enter a short section of transition duct and gas distribution system ahead of the 2 field electrostatic precipitator (ESP). Exiting the ESP the gases pass on to an induced draft (ID) fan, and discharge through a breeching into a stack. The circular stack contains two oval stack flues, one for each unit.

The ESP rappers on both stages are cycled continuously such that one row raps each minute.

3.6 Ash Removal

The original bottom ash handling system required manual ash removal through doors below the grate discharge. The original fly ash system was a dry pneumatic type. Both have been replaced with wet pit conveyor systems.

Short drag chain conveyors discharge the wet ash from the grate and ESP wet pits onto conveyor belts. The conveyors remove the ash to the yard outside the building. Ash is periodically moved from the yard to the on-site storage area by front end loader.

4.0 INSTRUMENTATION AND SAMPLING PROCEDURES

4.1 Overview

The overall extent of instrumentation installed and sampling locations for the program is illustrated in Figure 4. In addition to the existing plant control and monitoring systems, additional facilities were installed for the test program:

1. To monitor control room data
2. To monitor and measure combustion air and flue gas flows.
3. To accomplish non-disruptive observations of conditions within the furnace.
4. To measure air supply static pressures.
5. To monitor temperature regimes under the grate and within the furnace.
6. To continuously measure the flue gases for oxygen (O_2), carbon dioxide (CO_2), carbon monoxide (CO), and total hydrocarbons (THC)
7. To sample the flue gases at the outlet of the air heater to determine volumetric flowrate, particulate carryover, combustible content of the particulate, and moisture content of the flue gases.
8. To sample the fuel and ash stream and measure ash flowrates.
9. To record the data collected.

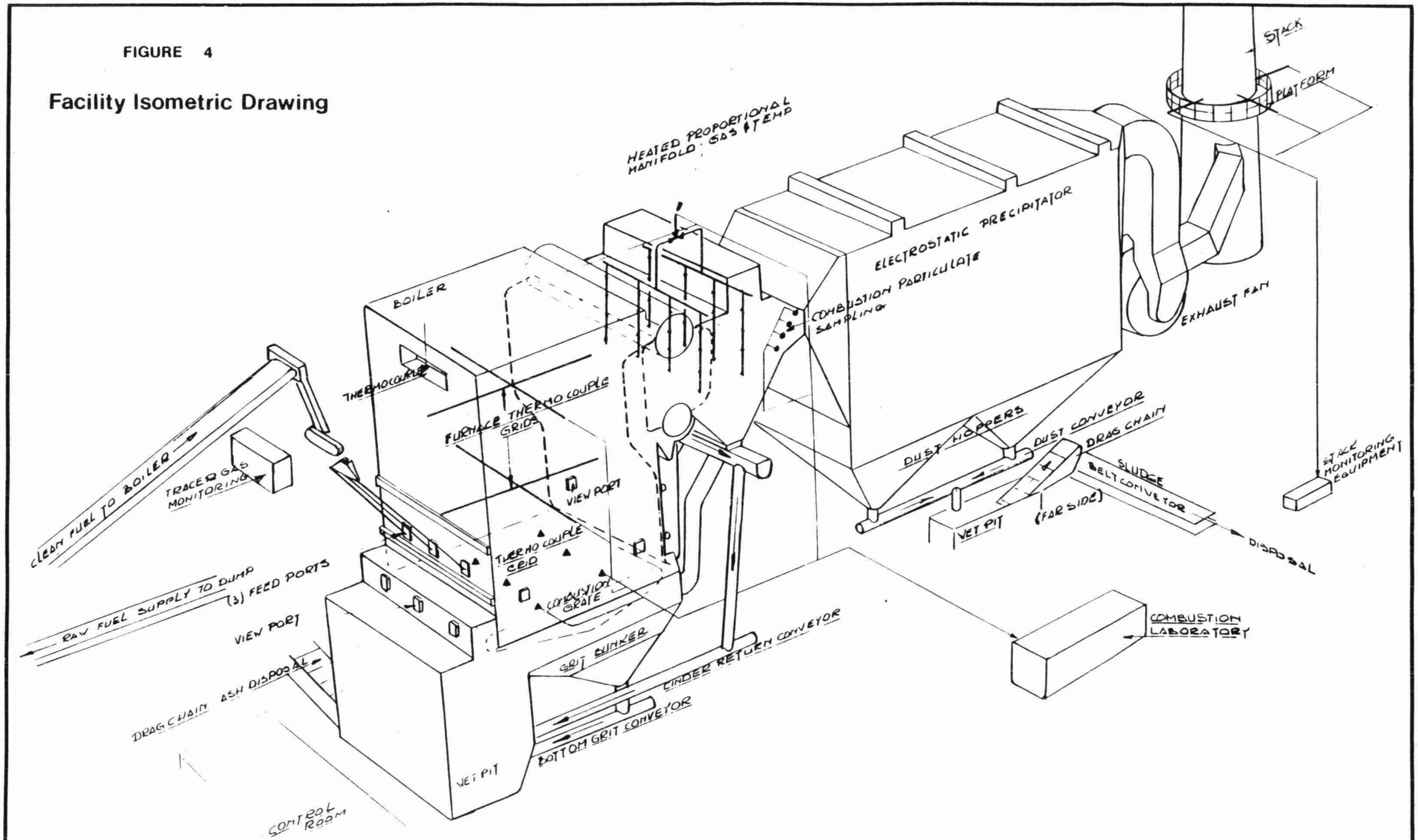
The following sections describe specific aspects of the above.

4.2 Control Room Monitoring

The control room was continuously manned by two technicians who logged pertinent control room data at 10 minute intervals.

FIGURE 4

Facility Isometric Drawing



4.3 Tracer System Gas Monitoring

Undergrate air, overfire air, flue gas flows, and feed chute infiltration air flows were routinely measured by a helium tracer gas monitoring system. The two prime components of this system are a mass flow meter and a mass spectrometer. Peripheral equipment included tygon sampling lines, line coolers and condensers, and a vacuum pressure pumping system. Tracer gas injection and sampling points are shown on Figure 5.

For the flue gas flowrate, tracer gas injection was either at the FD (location IA) or overfire air fan inlet (IB) and sampling immediately upstream of the air heater.(S1)

To determine the undergrate air flowrate, the tracer gas was injected at the FD fan intake (IA) and sampling was at the undergrate air duct before the air heater.(S3)

The overfire air flowrate was determined by injecting the tracer gas at the fan air intake (IB) and sampling was at the the overfire air fan discharge (S5). Feed chute infiltration was determined by injecting the tracer high up in a feed chute (IC) and sampling near the inlet to the furnace (S6).

During non-essential sampling periods, several experiments were conducted to determine the cinder return conveyor flow direction and magnitude and the leakage through the air preheater.

4.4 Viewports

Special ports designed for viewing the furnace conditions without affecting furnace draft or performance were installed initially at three locations, and later at two additional locations.

FIGURE 5

Tracer Gas Flow Schematic

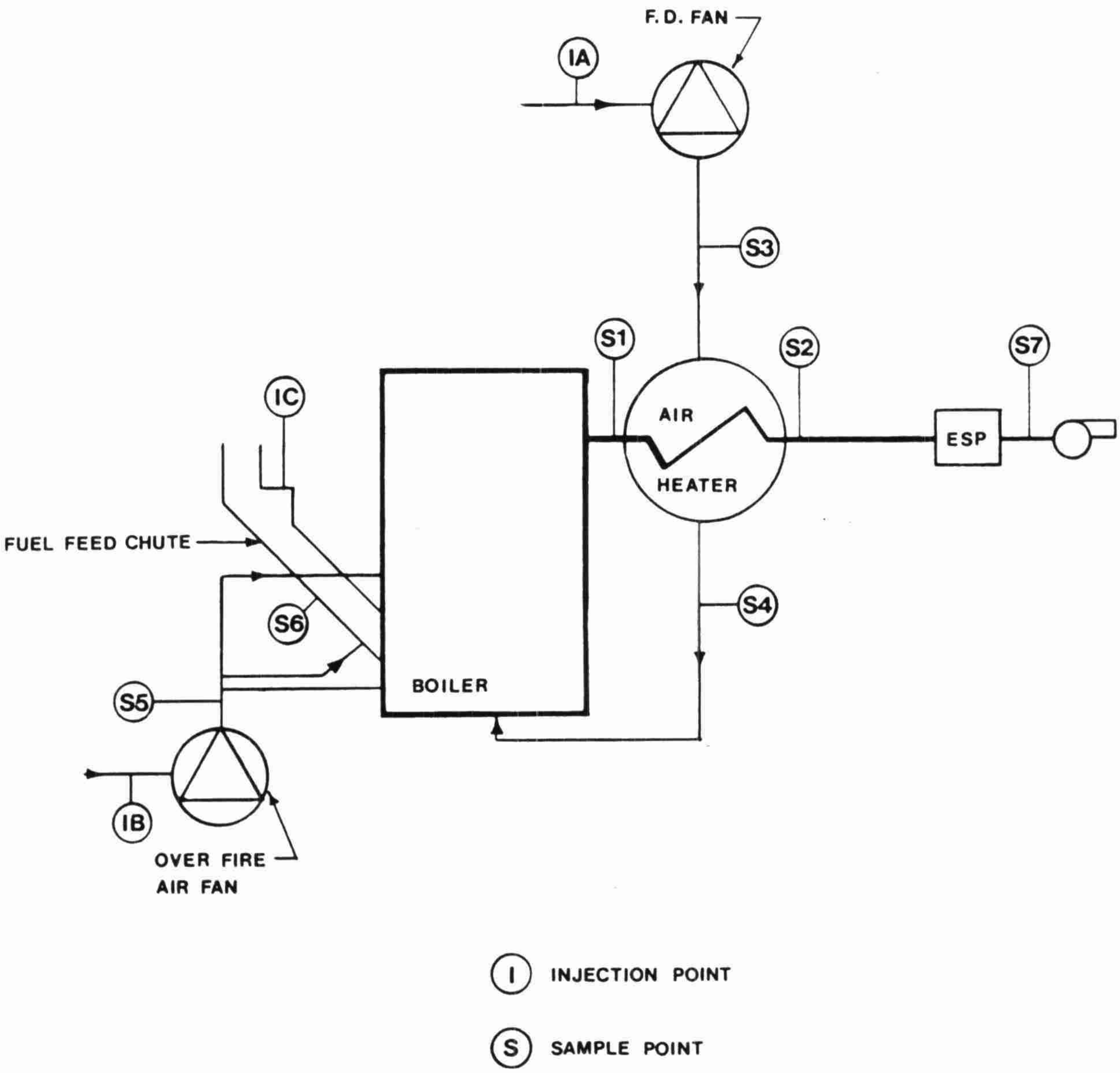
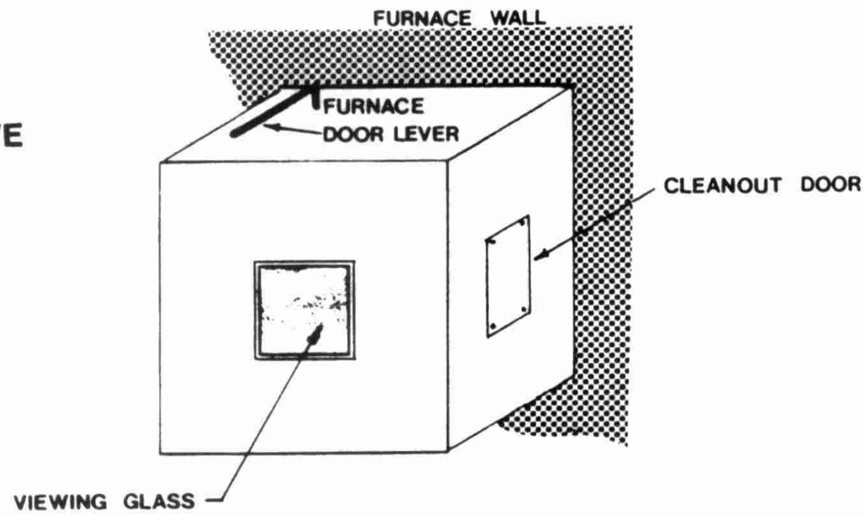


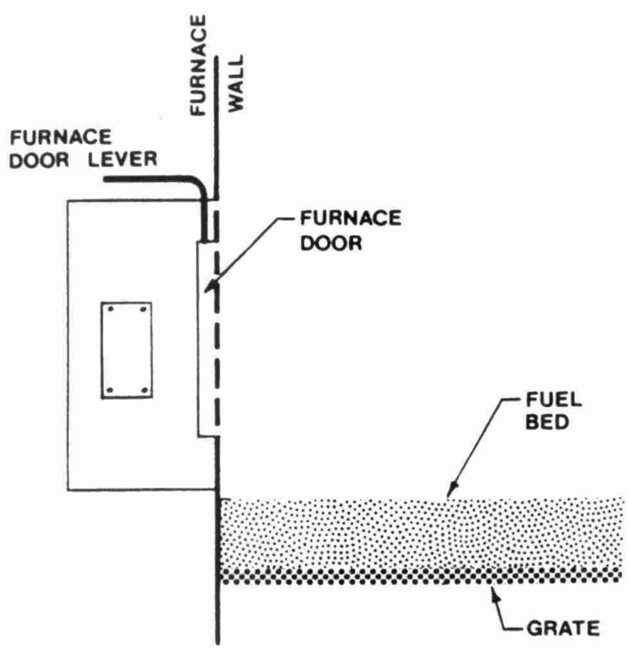
FIGURE 6

Observation Viewport

PERSPECTIVE



SIDE ELEVATION



The general port design is illustrated in Figure 6, and consisted of a box which encloses a furnace door or counterweighted plate. A tempered glass plate was installed on the front face of the enclosure box, and a door/plate opening handle extended through the box. Non-disruptive inspection of the furnace was accomplished at any time by opening the door/plate and viewing through the glass.

The three initial ports were added to the middle furnace front inspection door and the front and rear inspection doors on the right side of the furnace as shown in Figure 4. The front port was virtually at grate level and facilitated inspection of the grate, and suspension firing in the furnace. The side ports were somewhat higher than grate level. The rear port facilitated inspection of the rear grate seals and any fuel buildup at the juncture of the grate and back wall. The front port was used to observe fuel entry, bed condition and flame in the furnace.

Additional ports were added during the program near the vertical mid-point on the right side of the furnace and at the boiler bank level at the left side of the furnace. These ports facilitated observation of conditions in the upper areas of the furnace.

4.5 Static Pressure Measurement

Sampling points, tygon tubing and U-tube water manometers were installed for measuring static pressure at the following locations:

1. The feed chute supply plenum.
2. Each of the three feed chute air inlets.
3. Each of the four overfire air plenums.
4. The overfire air fan discharge header.

These pressures were recorded at frequent intervals.

4.6 Furnace Temperature Measurement

Temperatures within the furnace were measured on two levels. At each level multiple thermocouple probes extended from front to back and left to right at the furnace centrelines, shown in Figure 4. Type K thermocouples were installed at one foot intervals on air-cooled stainless steel pipes. Figure 7 illustrates the high temperature furnace probe assembly. A single thermocouple was installed to measure the top furnace temperature.A grid of six thermocouples were peened into the support steel of the furnace grates.

4.7 Continuous Flue Gas Monitoring

4.7.1 Overview

A continuous flue gas monitoring system was used to extract, transport, condition and distribute a representative flue gas sample to continuous analyzers with minimal alteration of the gas composition. Sample conditioning and continuous gas analysis was performed by Envirocon's Mobile Combustion and Emission Laboratory (MOCEL).

4.7.2 Sample Extraction

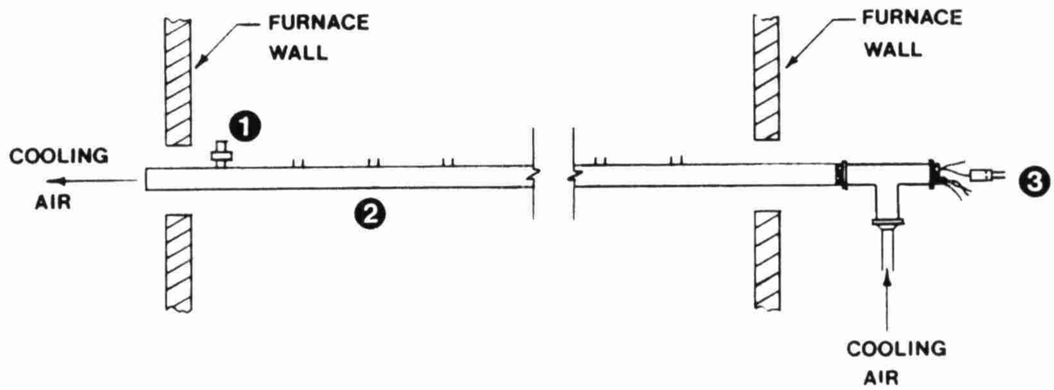
Two proportional gas manifolds were installed, one before and one after the air heater.

Four sample ports were installed at each location and four sample probes were inserted into each port. Each probe had its own proportioning valve in-line. The two groups of 16 sample probes were connected to separate manifolds.

All components external to the ports were heated and insulated and were constructed of stainless steel or teflon to minimize the contamination of the sample due to corrosion.

FIGURE 7

Typical Furnace Temperature Probes



KEY

1. SHEATHED S.S. THERMOCOUPLE (TYPICAL)
2. PIPE WITH THERMOCOUPLES MOUNTED AT 1' INTERVALS
3. THERMOCOUPLE PLUGS

4.7.3 Sample Conditioning and Transport

The inlet and outlet manifolds were connected through a three way valve to the sample transporting line. The transporting line was equipped with thermostatically controlled heat tracing and was insulated.

Particulate removal was accomplished by drawing the proportional manifold gases through both Balston filter and a spun glass fibre filter.

The combination of coarse and fine filtration ensured the complete removal of particulate above one micrometer in size.

A compressed air backpurge system was used periodically to purge the coarse particulate filter and sample lines. In addition to the routine and automatic backpurging, the sampling assembly was set under a slow purge during non-test periods.

The sample interface system used two permeation distillation dryers in series for dew point reduction without sample loss by dissolution in the condensate. The permeation process reduced water vapour contents of greater than 35% (V/V).

Gases were transported through the heated sample lines, particulate and moisture removal systems, and sent to the distribution and dilution module by a twin cylinder, Teflon-coated diaphragm pump located downstream of the particulate removal filters and primary dryer.

An automatic flow control system was used to maintain a constant flow through the entire interface system under varying pump suction vacuums and delivery pressures.

The gas distribution system transported precisely regulated quantities of sample gases to the continuous pollutant analyzers.

The system was routinely leak-checked to avoid dilution. Interference was minimized by the use of Teflon glass, Teflon-coated metals, and small amounts of stainless steel. Frequent water flushing of the sample lines removed any particulate matter which may have collected on the internal surfaces to cause sample loss by absorption.

4.7.4 Continuous Gas Analyzers

The continuous gas analyzers were rack mounted in the mobile laboratory. Continuous analysis of CO, CO_2, total Hydrocarbons and O_2 was carried out. The specifications of the indivdiual analyzers are noted in Table 2.

Prior to a run, zero, span and calibration checks were conducted on the instruments using certified calibration standards. Between traverses and at the end of a run this procedure was repeated to ascertain instrument drift.

4.8 Isojet Sampling

The Isojet sampler was used to obtain a large particulate sample from the flue gas after the air heater over a short time period. A sampling probe with a nozzle diameter of 10 cm was used to maintain isokinetic sampling conditions. A sampling rate of 85 to 170 m^3/h was achieved using a steam eductor system. As burning particulates travelled through the sampler they were extinguished by a steam quench. A large-capacity, high-temperature tared filter bag was used to collect the fly ash.

The sampling was conducted by traversing the flue cross secton at pre-determined points.

At the end of a run, the bag was removed and, after conditioning at 105 C to dryness, was weighed to determine total weight and combustibles content of the catch.

FIGURE 11 - AIR DRY MOISTURE RESULTS FOR TESTS 10-1 and 19-1

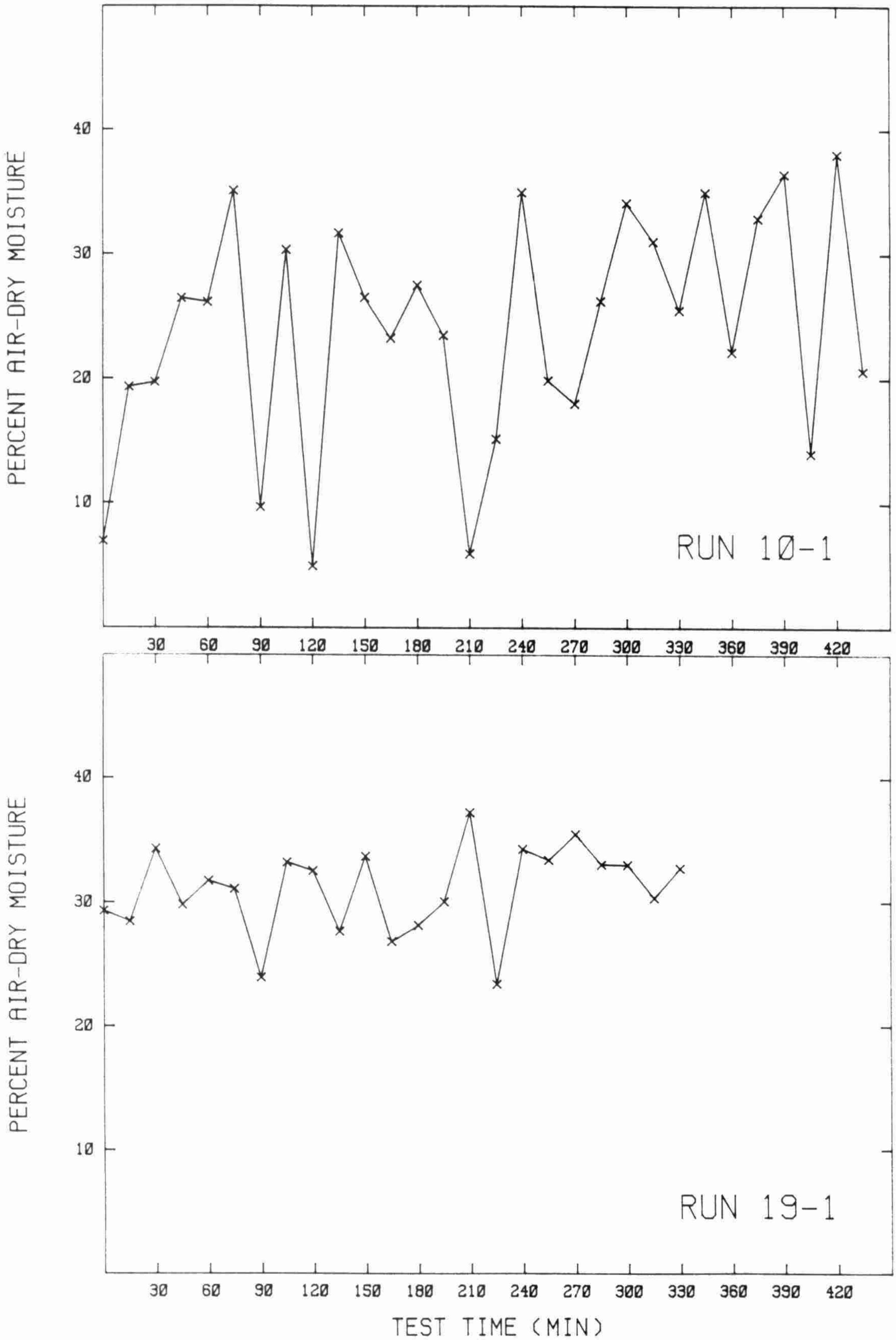


TABLE 2: CONTINUOUS ANALYZERS

Carbon Monoxide

Type: Infrared absorption

Manufacturer: Infrared Industries Inc., Model IR703d2-002 Gas Analyzer

- Range 0-1.00 ppm x 1000, 0-10. ppm x 1000
- Accuracy ±1% full scale
- Span drift ±1% of full scale in 24 hours
- Zero drift ±1% of full scale in 24 hours.

Carbon Dioxide

Type: Infrared absorption

Manufacturer: Infrared Industries Inc., Model IR702 Gas Analyzer

- Range in percent 0-5, 0-20
- Span drift ±1% of full scale in 24 hour
- Zero drift ±1% of full scale in 24 hour
- Accuracy ±1% of full scale

Total Hydrocarbons

Type: Flume ionization

Manufacturer: Horiba Instruments Inc. Model FIA-21

- Range 0-10/30/100/300/1000/3000/10000/30000 ppm carbon
- Accuracy is ±1% full scale for successive identical samples
- Span drift ±1% of full scale in 8 hr

Oxygen

Type: Paramagnetic

Manufacturer: Taylor Servomex Ltd., Type OA.137

- Range 0-2.5, 0-5, 0-10, 0-25,0-100
- Accuracy ±0.05% oxygen or ±1% full scale, whichever is the greater

Moisture determination was carried out at the same location in accordance with the Ontario Source Test Code Method 4, (5) with the exception that sampling was not proportional.

4.9 Fuel and Ash Sampling

Fuel samples were taken at the transfer point between conveyors #6B and 78. To ensure that a representative sample was taken, the sampler swept the shovel through the complete width of the falling stream of waste. Each individual sample was composed of three shovel loads, taken over a fifteen minute period. Sampling commenced at the start of each test and continued non-stop until the end of test. Individual samples were bagged, and stored in metal drums lined with heavy gauge plastic.

Ash samples were taken at the following locations:

1. dry ash off the grate
2. wet ash from the grate ash removal conveyor
3. dry ash from the ESP hopper discharge
4. wet ash from the ESP wet ash removal conveyor

With the exception of the dry ash from the grate, which was sampled after each test or diagnostic sampling traverse, samples were taken every 15 minutes. Samples were placed in a glass jar until the jar was full. Filled jars were sealed and inventoried.

During each traverse of the diagnostic tests, collection bins were installed at the discharge of the grate and precipitator ash belt conveyors for at least one hour. The total weight of bottom ash collected was recorded. It was necessary to decant the water from the precipitator ash catch before weighing to record ash weight.

The air dry moisture content of the fuel was measured using the basic methodology specified in ASTM E829-81. The samples were weighed, then spread out on large plastic sheets to air dry. The rate of drying was monitored by periodic reweighing of a number of control samples.

The size distribution of selected fuel samples was determined using a 0.6 m x 0.6 m (2 ft x 2 ft) seiving assembly equipped with Tyler 5 cm (2") and 1.3 cm (1/2") sieves. The samples were seived according to the ASTM E828-81 method.

4.10 Data Acquisition System

The MOCEL data acquisition system was designed to scan thermocouple and lab instrument channels at specified time intervals, and to record this data on hardcopy and, on diskette for subsequent analyses and processing. The major components of the data acquisition system included a datalogger, microcomputer and a matrix printer.

4.11 Dioxin, Furan and Precursor Sampling

The sampling related directly to dioxin, furans and precursors was undertaken by Ontario Research Foundation (ORF) under a separate contract. The program included stack sampling, grate and precipitator ash sampling, and pulverized fuel sampling.

The methodology is described in detail in 'Stack Sampling for Trace Organic Contaminants (Version 5 - SWARU)', developed by the Source Measurement Unit of the Ontario Ministry of the Environment. The stack sampling uses three EPA5 type trains modified to contain two fluorisil tubes after the impingers. Collection of the bottom ash, fly ash, and feed samples taken during the stack sampling. Grate ash samples for trace organics were taken immediately before the initiation of each traverse. Details are contained in ORF Report P-4318/G (Revised) Draft, December 2, 1983.

The samples were analyzed for the substances listed in Table 3 by the MOE Laboratory Services Branch.

TABLE 3
DIOXINS, FURANS AND PRECURSORS ANALYZED

A. Polychlorinated dibenzo-p-dioxins (PCDD)

- tetrachlorodibenzo-p-dioxins (TCDD)
- pentachlorodibenzo-o-dioxins (P5CDD)
- hexachlorodibenzo-p-dioxins (H6CDD)
- heptachlorodibenzo-p-dioxins (H7CDD)
- octachlorodibenzo-p-dioxin ((OCDD)

B. Polychlorinated diobenzofurans (PCDF)

- tetrachlorodibenzofuran (TCDF)
- pentachlorodibenzofuran (P5CDF)
- hexachlorodibenzofuran (H6CDF)
- heptachlorodibenzofuran (H7CDF)
- octachlorodibenzofuran (OCDF)

C. Polychlorinated biphenyls (PCB) (trichlorinated to heptachlorinated)

D. Polychlorinated phenols (dichlorinated to pentachlorinated)

E. Polychlorinated Benzenes (trichlorinated to hexachlorinated)

5.0 DISCUSSION OF RESULTS

5.1 Inspection and Cold Tests

The first internal inspection of the boiler indicated that the bulk of the holes in the grates were plugged with ash deposits and, in some cases, with previously melted metal. In addition, the furnace rear seals were seized such that there was a large open space between the top of the grate and the bottom edge of the seal.

This inspection also revealed that the feed system into the furnace had been revised to eliminate the original wind-swept spouts and the hinged plates in the chute above the spout, which minimized induced air entering with the fuel. The present arrangement is an open chute which permits a flow of air into the furnace with the fuel. The air slots in the revised design had a very irregular upper edge, and varied in height across the slot from approximately 1.3 to 4 cm (1/2 to 1 1/2 in).

This inspection also indicated that the lower OF air port plenum was nearly full of a built-up cake of ash and dust, and that many of the overfire air port jets (which were not used prior to the program) had collected ash and dust deposits. The membrane walls were found to be fairly clean with some buildup of ash and slag on the back wall below the feed chute level. The inspection also revealed a heavy buildup of ash and dust in the flue leading to the precipitator and buildup around the lower section of the air heater.

The grates, grate holes OF plenums and OF jets were subsequently cleaned, and the rear seals were maintained so that they were functional. Inspections over the balance of the program showed a gradual buildup of deposits in the grate holes but very little buildup of deposits in the OF jets or air plenums.

Dust buildup in the duct leading to the precipitator was removed prior to the test and at weekly intervals during the balance of the program.

The cold flow tests were undertaken after the first internal inspection and after the grate and OF air system had been cleaned out and the seals were serviced.

The single most notable observation during the cold tests was the air stream caused by the feed chute air. The very high velocity stream from the feed chute penetrated beyond the furnace centreline, and caused flow chanelling up the back wall of the furnace, leaving a large relatively stagnant zone in the furnace above the feed chutes. In tests with the rear overfire air ports dampers open, there was still marked penetration by the feed chute air, but the chanelling effect at the rear wall was significantly reduced and the stagnant zone was no longer evident. The cold tests also indicated uneven distribution of the undergrate air through the grate.

5.2 Combustion Runs

5.2.1 Introduction

Combustion runs were carried out as a preliminary to the diagnostic tests. The intent was to operate the test boiler for short periods under controlled firing conditions to assess the effect of varying parameters including boiler load.

Initially, the schedule for combustion runs envisioned many short runs to be performed in rapid succession with only sufficient time between runs to make adjustments and obtain steady operation for the next test. In actual fact many problems were encountered with process equipment deficiencies which caused delays. As more and more of these deficiencies were rectified it became increasingly apparent that the control of fuel to obtain reasonably satisfactory steam pressure and steam flow conditions was beyond the capability of the system as presently installed, despite the best efforts of the operators.

The design of the feed conveyors with their sharp directional change caused flow continuity problems. Current operating policy calls for gradual introduction of refuse to the pit by front end loader or direct truck transfer, to hold a body of refuse in the area of the incline only. However, this does not prevent balling and tumbling of the refuse and occasional bridges which must be removed by portable crane. This balling, tumbing and bridging causes variations in the rate of feed to the individual pulverizers.

At the beginning of the test program, a significant number of the angle iron flights on the feed conveyors were either missing or damaged. During the second week of the combustion tests, a contractor replaced over 10% of these flights and repaired some additional flights. Prior to the improvements in the conveyor flights, levelling of the refuse on the conveyors proved to be extremely difficult. Even after the flights were improved, the best attempts at levelling were not sufficient to avoid very heavy conveyor loadings at certain times and almost bare conveyor sections at other times.

Combustion air could be effectively adjusted and maintained as desired to produce steady flows for the duration of a run.

During each combustion run the operation was as follows:

1. F.D. Fan - the FD fan was placed on automatic control to maintain a constant pressure in the duct after the air heater.

2. Undergrate Air - the damper control was adjusted to obtain the desired air flow and left in the "hand" position thus fixing the position of the damper and providing a constant flow.

3. Furnace Draft - the ID fan was placed on automatic control to maintain a constant furnace draft and remove the products of combustion and excess air from the furnace.

4. Overfire Air - the overfire air was maintained constant by locking the manual discharge damper at the fan outlet and locking all dampers to the various overfire air port plenums and the plenum to the distributor fuel feed chutes.

5. Steam Pressure - during the tests the steam turbine - generator set was out of service. The only control of steam pressure was by means of pressure release (PRV) valves. These could be operated in an automatic or manual mode. Several attempts were made to use the automatic mode but despite adjustments the valves would not perform satisfactorily. Runs were therefore carried out with the PRV valves on hand control, and this resulted in constant pressure variations. Variations in pressure produced errors in the accuracy of the steam flow meter and this, in turn, made operation to a designated steam flow an impossibility.

6. Steam Flow - steam flow was intended to be controlled by boiler fuel feed rate, which was controlled by the speed of the conveyors to the pulverizers. The operators were permitted to select the number of pulverizers in service and whether the conveyors were operated in the manual or automatic mode.

   The operator in the control room had no control over the quantity of fuel on the conveyor as it travelled to the pulverizer. This in part was dependent on the amount of material in the pit and whether there were problems of bridging or balling on the conveyor.

Response time to a change in conveyor speed was slow since transport time from the pulverizers to the boiler front was in the order of two and a half minutes.

5.2.2 Boiler Load

Discussions with operating personnel disclosed the general opinion that the maximum steaming output was in the order of 10 kg/s (80,000 lb/h) and the minimum load was generally in the order of 5 kg/s (40,000 lb/h). Lower loads were said to be attainable but were never required for any duration of time.

On the basis of this information, the decision was made to undertake combustion runs at the higher and lower values and at the mid-point between the two, nominally 7.5 kg/s (60,000 lb/h).

On the first two days of combustion runs problems were experienced in achieving a steady load at the designated mid-point value.

Attempts were made on April 15 and again April 20 to test at a higher load of about 10 kg/s. Problems were experienced in controlling the required amount of fuel to the furnace and smoke emissions were frequent and heavy. On April 20, the designated load was dropped to about 9 kg/s (70,000 lb/h), and for the remainder of the day the opacity readings were consistently lower with a major reduction in the number of spikes in opacity recorded.

The decision was then made that combustion tests would be conducted at two designated levels rather than three, nominally at 5 kg/s and 9 kg/s.

During all combustion tests problems were experienced with controlling the fuel to provide reasonably steady steam header pressure and steam flow.

5.2.3 Undergrate Air Flow

During each combustion run, the air flow control was in the manual mode and air flow to the undergrate compartment was maintained constant during the run.

At the start of each combustion run day, the operator selected the value for undergrate air flow which would normally be used with respect to the firing rate and furnace conditions. In all instances, the selected setting contributed to high excess air as indicated by high levels observed on the continuous oxygen analyzer. During the day adjustments were made to the undergrate air flow in an attempt to lower the quantity. Changes in furnace conditions and opacity of the flue gases were noted.

It is to be noted that not all air to the undergrate air flows through the grates to the fuel bed. The rear grate seals as originally designed by the stoker manufacturer have been removed. The present seals are poorly fitting and are hinged to pivot from the back wall to ride on the moving grate surface. In this position there is a large gap across the top of each seal which permits undergrate combustion air to by-pass the grates and enter the furnace at the rear wall. During operation of the unit it is not possible to see the position of the grate seal. However on more than one occasion they were found to be frozen in a raised position above the travelling grate. In this position air sweeps under the seal along the grate rather than upward into the furnace. Air by-passing the grate disturbs the fuel bed and the adversely affects burning conditions in the lower furnace.

5.2.4 Overfire Air Flow

Combustion runs were carried out with different combinations of ports in service. The use of the lower back ports appeared to improve furnace conditions and generally resulted in a reduction in pile build-ups at the back of the grates.

Transport air to the feed chutes on the boiler front wall is supplied from the overfire air fan. High static pressures, in the order of 15 cm (6 in) water column, tended to throw the fuel across the furnace and hit the back wall. Slightly lower static pressures, in the order of 7.5 to 10 cm (3 to 4 in), produced better fallout on the rear position of the grates.

5.3 Diagnostic Tests

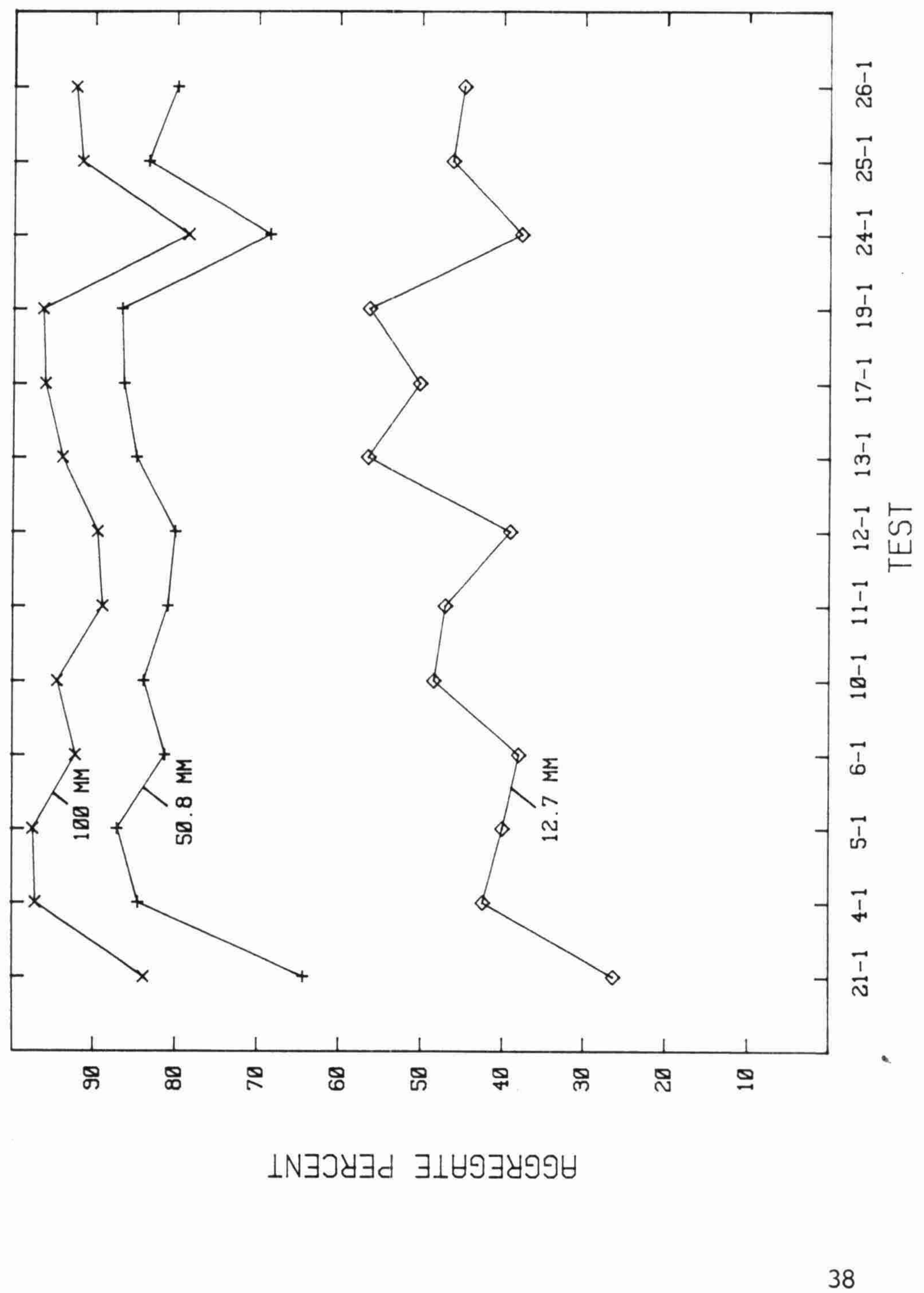
5.3.1 Fuel Preparation and Properties

The bulk of the results related to fuel preparation and properties is shown for each test in Appendix II. This data is discussed and additional data presented in this section.

Figure 8 shows the size distribution of the fuel plotted sequentially for the diagnostic tests. On average over the tests, about 9% of the material was preseparated as having a major dimension larger than 100 mm (4 in), another 11% was retained on the 50.8 mm (2 in) screen, 37% was between 50.8 mm and 12.7 mm, (0.5 in) and 43% passed through the 12.7 mm screen.

This size distribution data clearly illustrated that there are considerable day-to-day variations. For Test 5-1, the oversize constituted only 2.7%, while for test 24-1 it constituted 21.5%. The fraction below 12.7 mm ranged from 22.2% for Test 21-1 to 56.4% for Tests 12-1 and 19-1.

FIGURE 8 - SIEVE ANALYSIS RESULTS FOR ALL TESTS



For tests 12-1 and 13-1 the normal for changing hammers practice on the pulverizers was modified by the plant personnel. The result of this modification is not obvious from the size distribution data obtained, in that the results on these two days are within the range of variation over the program.

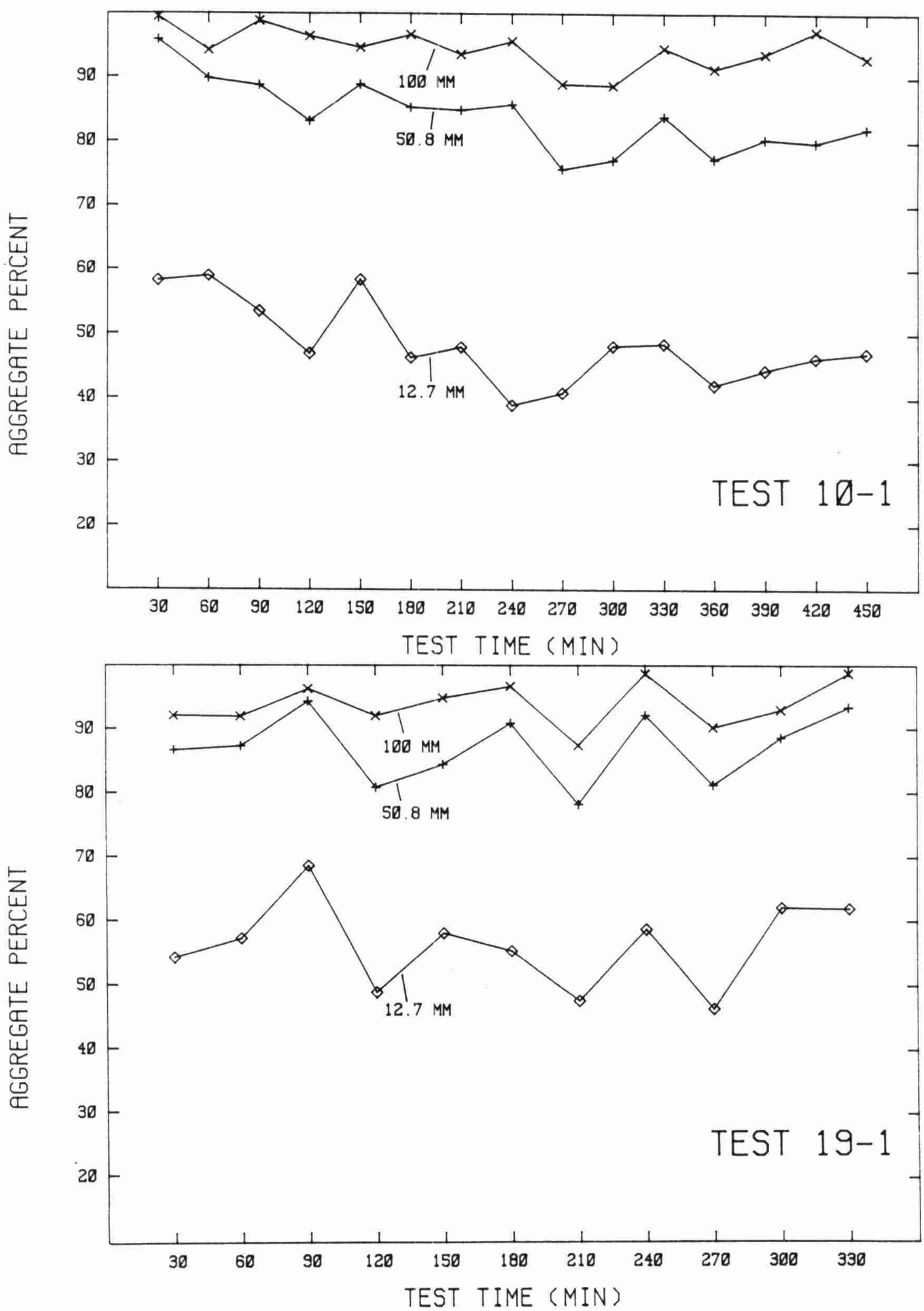
Figure 9 shows the variation of fuel size distribution over the course of tests 10-1 and 19-1. These results show considerable variation between the measurement intervals. The results from test 10-1 show a general trend over time of less material passing through the 12.7 mm screen and the 58.8 mm screen, suggesting some deterioration in the pulverizer effectiveness. A similar trend is not obvious for test 19-1.

Figure 10 shows the average and standard deviations of the air-dry moisture content of the fuel for the diagnostic tests. The fuel moisture variation was clearly significant, ranging from a minimum of 22% to a maximum of 30%.

However, the variations in average air-dry moisture content from one run to the next are much smaller than the variations in size distribution. There appears to be a fairly regular decrease in moisture content during the week of 3 May (tests 4-1 through 6-1), a gradual increase in moisture content through the next week (tests 10-1 through 13-1) and slight increase through the balance of the program.In addition the standard deviations are considerable, up to 9.5%, and vary from run to run.

Figure 11 shows the variation of air-dry moisture content over the course of tests 10-1 and 19-1. The levels for test 10-1 are extremely variable between the 15 minute interval of measurement and throughtout the run; levels for test 19-1 are lower but still signficiant.

FIGURE 9 - SIEVE ANALYSIS RESULTS FOR TESTS 10-1 and 19-1



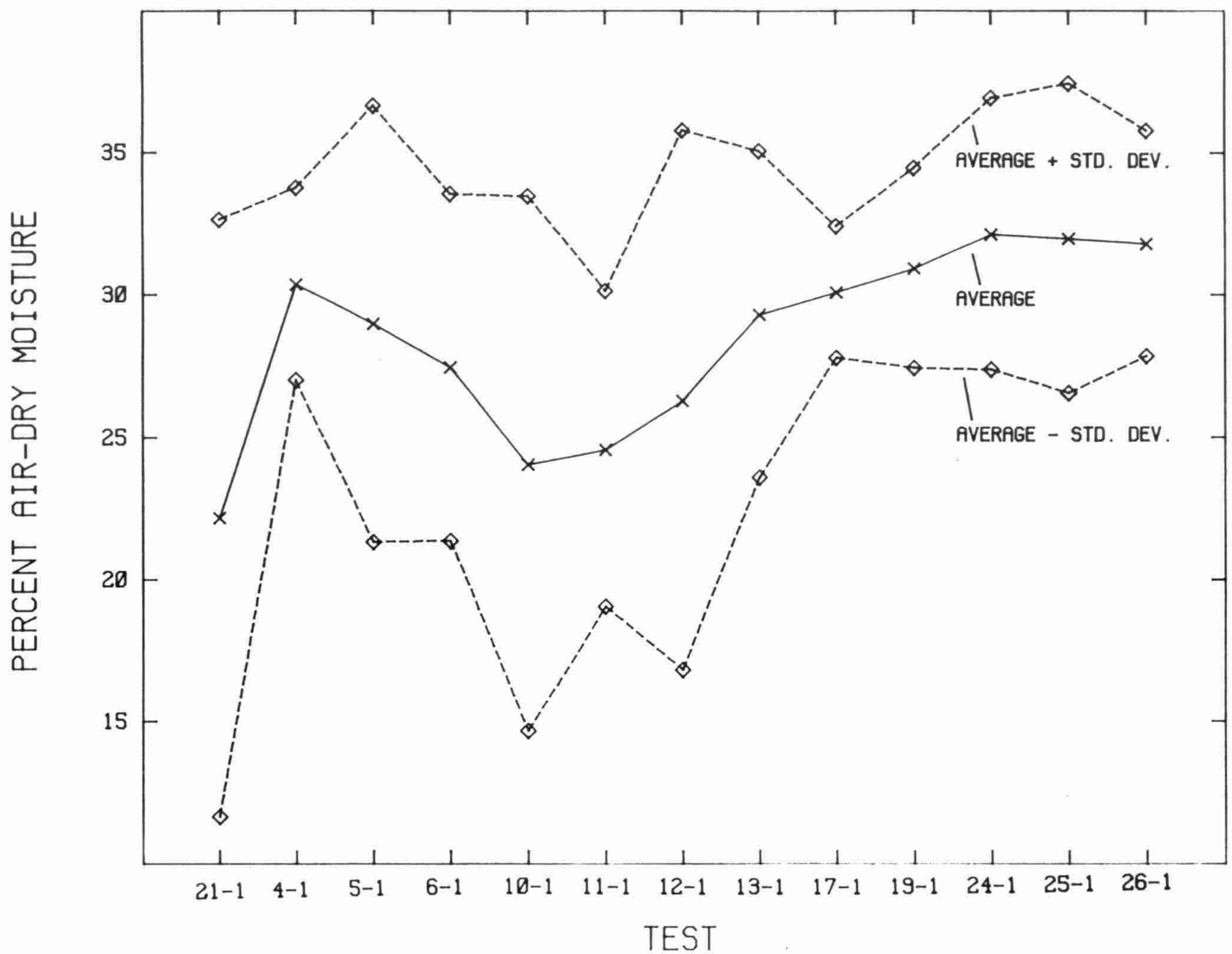


FIGURE 10 - AIR DRY MOISTURE RESULTS FOR ALL TESTS

A further indication of the range of fuel properties is shown in Figure 12. For complete uniform combustion of a fuel with constant ultimate analysis, points representing individual tests should lie on a straight line Reference: (ASME PTC 4.1 - 1972). In the case of the diagnostic-test average gas analyses, this is clearly not the case. Projecting lines from the pivot point through the tests at or below 250% excess air projects a maximum of 19 to 21% CO_2; if all the tests are included, the upper end of the range extends to 22%.

Table 4 shows the laboratory results for residual moisture, ultimate analysis, and calorific value for three reduced samples from each of tests 10-1 and 19-1.

The samples show a broad range of values, particularly for ash content. Average calorific values also show a broad range, with the first sample for Run 10-1 being signficantly lower than the other values. The air-dry plus residual moisture values for these runs result in total moistures of 30.6 and 38.0% respectively.

These broad and significant changes in fuel properties both in the short term and day-to-day do not necessarily show the total range of variation of the refuse received but do suggest that the range of municipal refuse fuel properties found by others are reflected at the SWARU plant.

Table 5 shows the results of the dioxin, furan and precursor analysis of the fuel samples, as reported by Ontario Research Foundation.

The fuel data indicates highly variable amounts of the compounds measured. Since the samples taken for these analyses were small and were taken at fairly infrequent intervals, care should be taken in the use of the individual analysis for each run as being generally representative of the amounts of each substance which enter the furnace for that particular run.

In addition to the variability of the fuel as received, the fuel preparation system has a major effect on the delivery of fuel to the boiler and it's subsequent burning.

FIGURE 12 - FLUE GAS COMBUSTION CHART

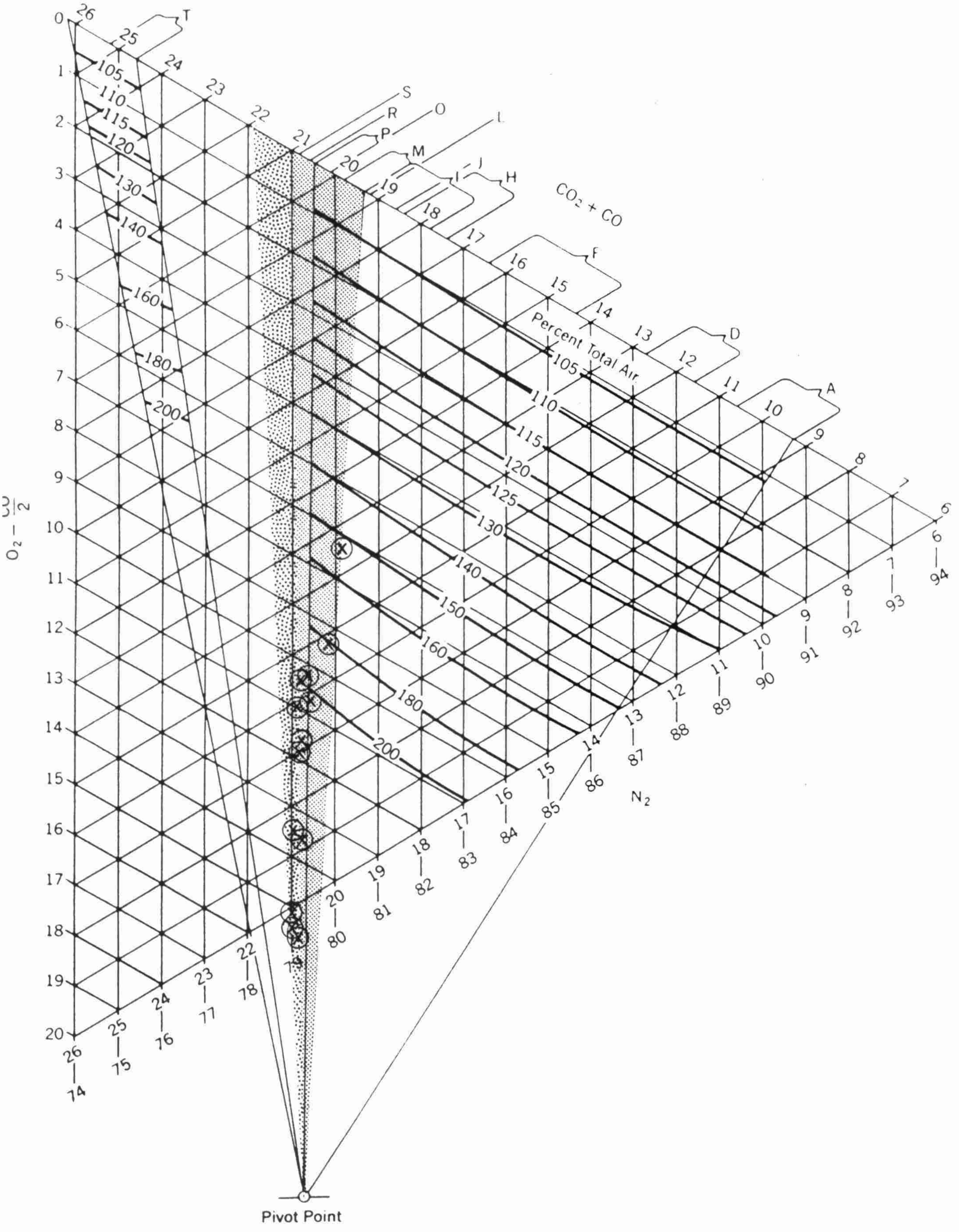


TABLE 4
ANALYTICAL RESULTS FOR FUEL SAMPLES

SAMPLE	RESIDUAL MOISTURE %	DRY BASIS ULTIMATE ANALYSIS ASH %	CARBON %	HYDROGEN %	NITROGEN %	SULPHUR %	OXYGEN %	CALORIFIC VALUE k Joules/g	(BTU/lb)
Run 10-1 T1	5.1	39.7	37.8	5.23	0.62	0.22	16.43	11.52	(4947)
T2	6.2	30.3	39.3	5.56	0.62	0.33	23.89	15.10	(6487)
T3	6.0	26.2	39.9	5.51	0.49	0.20	27.70	15.95	(6853)
Average ± Std. Dev.	5.8 ±0.6	32.1 ±6.9	39.0 ±1.1	5.43 ±0.18	0.58 ± .08	0.25 ± .07	22.7 ±5.7	14.19	(6095 ± 1011)
Run 19-1 T1	4.5	38.0	36.7	5.04	0.61	0.40	19.25	13.58	(5834)
T2	5.8	27.2	42.3	5.92	0.82	0.16	23.60	15.25	(6553)
T3	4.3	47.3	35.6	5.04	0.71	0.31	11.04	15.39	(6610)
Average ± Std. Dev.	4.9 ±0.8	37.5 ±10.1	38.2 ± 3.6	5.33 ±0.51	0.71 ±0.11	0.29 ±0.12	18.0 ±6.4	14.74	(6332 ± 433)

TABLE 5

DIOXIN, FURAN AND PRECURSOR CONCENTRATIONS IN FUEL SAMPLES

RUN	DIOXINS ng/g	FURANS ng/g	CHLOROBENZENES ng/g	PCB's ng/g	CHLOROPHENOLS ng/g
1	8.8	25.0	6.6	18.0	240
4	10.3	ND	8.0	10.0	260
5	4.0	4.0	3.6	800.00	128
6	3.7	ND	3.8	16.2	152
7	13.4	ND	44.0	30.0	300
8	6.5	ND	9.6	7.0	1
9	11.7	ND	10.0	6.4	176
10	17.3	ND	4.2	7.0	220
11	15.8	ND	9.2	26.0	640
12	9.6	ND	9.6	12.2	360
13	97.0	0.3	5.8	500.0	740
14	29.6	0.4	24.0	17.2	2000
15	29.8	ND	26.0	38.0	1560
Average	19.8	2.3	12.6	114.5	521.3

ND = None Detected

5.3.2 Combustion Air and Furnace

Based on the information obtained during the combustion runs, a program was developed which would have resulted in replicate diagnostic tests with various combinations of overfire air ports.

During the initial diagnostic runs, undergrate air flow was set on the basis of the values determined during the earlier tests.

The operation of the units for the tests were similar to that described in Section 5.2.1. The protocol for establishing boiler operating conditions was initiated by an evening notation in the operator's log as to the proposed steam load for the next day's test. The proposed steam load condition was also discussed with management representatives.

The operators were free to select all other operating parameters as they saw fit for the beginning of the test. The only criteria placed on parameters at that time was that the operators be mindful of the need to replicate the conditions for repeat tests.

Prior to the initiating testing, the Boiler Coordinator reviewed all relevant parameters and discussed items with the operator as necessary. During the test, the operators were requested to inform the Coordinator of any signficant changes that had occured or were to be made. If conditions appeared to have altered considerably, the Coordinator and operators discussed strategies to rectify the situation.

As the testing progressed it became necessary to raise the undergrate air flow to minimize clinkering on the grates and keep the ash on the bed dry.

High undergrate air flows were necessary for tests 21-1, 13-1, 19-1 and 24-1. It is to be noted that each of these tests were made with all the overfire air ports closed.

Heavy clinkering was also experienced on tests 17-1 and 26-1 which were run with overfire air in use. Some clinkering was experienced on all tests with the exception of 4-1 and 5-1.

Observations of the bed of material on the grate frequently indicated piling of the refuse behind the flame front. These piles, at times as much as a metre or more in height and width, tended to grow as the grate moved forward. The material in the piles remained substantially unburned; there was very little evidence of charring even on the surface, although smoke was generally observed rising from these piles.

These piles of fuel formed on the bed during all the tests with the exception of run 4-1 and 13-1. The frequency and extent of piling may have been in part the result of a change in fuel moisture or fuel quality. However it is more likely that much of the piling resulted from changes made in fuel feed in an attempt to maintain reasonably constant steam pressure and steam flow.

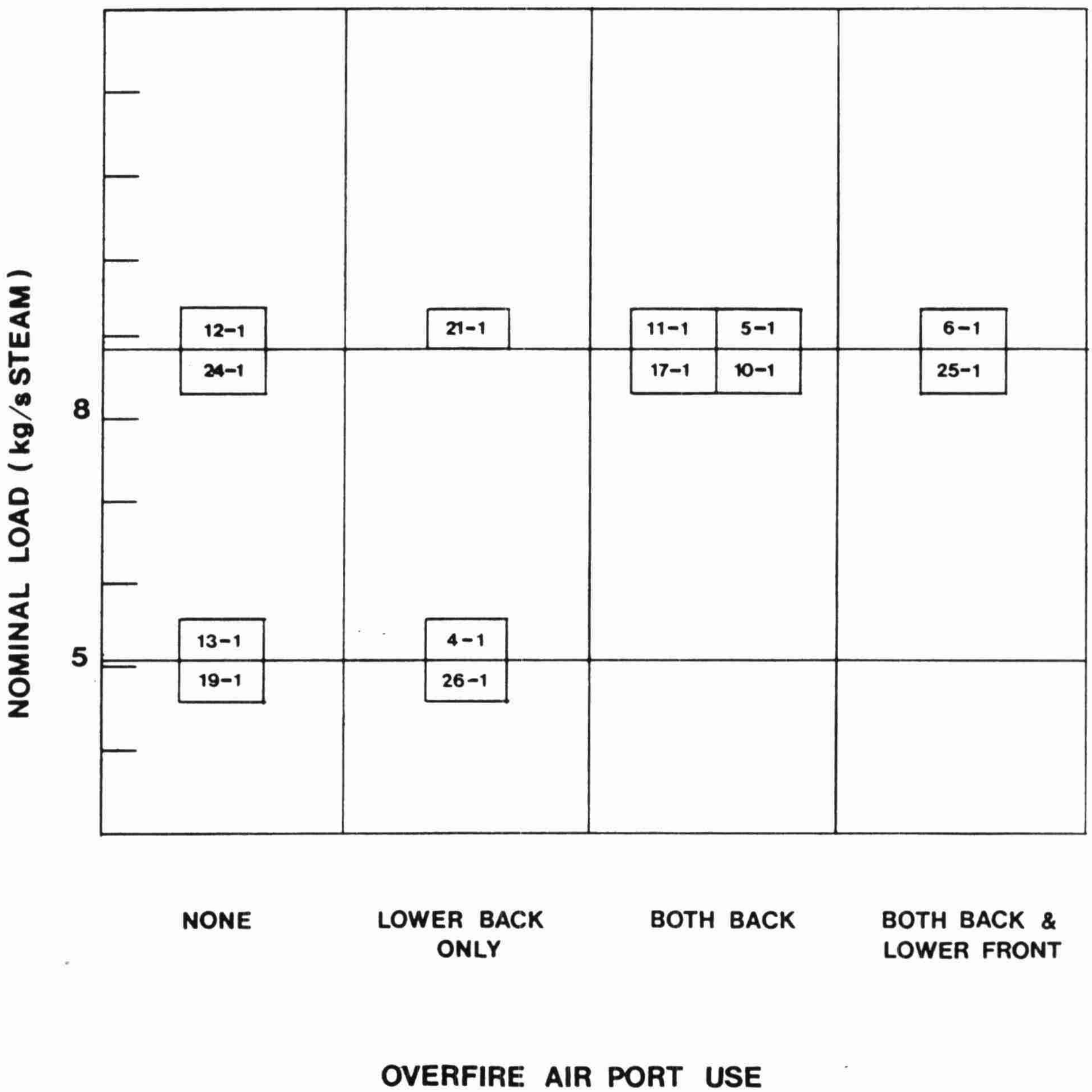
During the tests the steam pressure and steam flow varied widely despite the best efforts of the operators.

Figure 13 shows the final test matrix developed during the program. As indicated in the figure, duplicate tests were achieved at each matrix condition, with the exception of lower back overfire air port use at a nominal 9 kg/s steam load. However, because undergrate air flow changes were necessary, and steam flow and pressure varied widely, the overall conditions for these duplicate test attempts varied considerably.

Furnace conditions and furnace temperature data for individual traverses are

FIGURE 13

Diagnostic Test Matrix



summarized in Appendix II. Table 6 summarizes the averaged, minimum and maximum air heater exit gas, top, upper, lower and grate temperatures for the nominal 9 kg/s and 5 kg/s tests.

Based on the overall averages, the furnace temperatures for the nominal 9 kg/s tests were well above those for the 5 kg/s. For example the average top temperature for the higher loads was 96°C (205°F) above that at the lower loads. the maximum average top temperature for the nominal 9 kg/s test (Test 6-1) was 677°C (1250°F).

5.3.3 Flue Gas

Table 7 summarizes the averaged level and minimum and maximum values for O_2, CO_2, CO and THC concentration and frequency of CO and THC peaks for the nominal 9 kg/s and 5 kg/s tests. Data for the individual traverses of each test and overall test averages are shown in Appendix II.

Figures 14 and 15 illustrate sections of the continuous strip chart recorders for carbon monoxide (CO) and total hydrocarbons (THC) for tests 10-1 and 19-1. These figures illustrate that the levels of these two gases rise and fall simultaneously in time. Although the frequency of peaks in test 19-1 is much greater than for test 10-1, peaks in the THC concentration are accompanied by a similar peak in the CO concentration in both cases. A similar correspondence exists for all combustion tests and diagnostic runs.

Observations during the diagnostic tests also indicated that when there was a peak or series of peaks of CO and THC, there was piling of material on the grates. In fact, in a number of cases the sudden appearance of peaks of CO and THC corresponded in time to the observation of one or more piles moving forward out of the flame front. However, the reverse was not always the case.

TABLE 6
SUMMARY OF FURNACE TEMPERATURE DATA

NOMINAL STEAM FLOW 9 kg/sec (9 runs)

	Overall Average	Minimum Value	Minimum Run	Maximum Value	Maximum Run
Air Heater Exit					
Gas Temp °C	372	342	21-1	397	25-1
Top Temp °C	659	642	5-1	677	6-1
Upper Furnace					
Temperature °C	652	599	5-1	741	17-1
Lower Furnace					
Temperature °C	751	713	21-1	791	12-1
Grate Temp °C	245	231	12-1	264	25-1
Total Air %	214	155	21-1	294	25-1
Average Steam Flow kg/s	8.51	8.03	5-1	9.21	6-1

NOMINAL STEAM FLOW 5 kg/sec (4 runs)

	Overall Average	Minimum Value	Minimum Run	Maximum Value	Maximum Run
Air Heater Exit					
Gas Temp °C	317	312	4-1/26-1	323	19-1
Top Temp °C	563	538	4-1	587	19-1
Upper Furnace					
Temperature °C	576	508	4-1	636	19-1
Lower Furnace					
Temperature °C	604	547	26-1	659	13-1
Grate Temp °C	225	207	13-1	247	26-1
Total Air %	360	234	4-1	433	13-1
Average Steam Flow kg/s	5.12	4.86	4-1	5.48	19-1

TABLE 7
SUMMARY OF CONTINUOUS GAS ANALYSIS

NOMINAL STEAM FLOW 8.82 kg/sec (9 runs)

	Average Value	Minimum Value	Minimum Run	Maximum Value	Maximum Run
O_2 %	10.9	7.4	21-1	13.7	25-1
CO_2 %	9.7	7.1	25-1	12.4	21-1
CO PPM	383	252	6-1	518	21-1
THC PPM	90	12	11-1	220	21-1
THC Peaks/hr 600	2.59	.16	10-1	6.77	21-1
THC Peaks/hr 300	3.89	.24	11-1	10.65	21-1
CO Peaks/hr 1500	2.70	.47	11-1	7.26	21-1

NOMINAL STEAM FLOW 5.04 kg/sec (4 runs)

	Average Value	Minimum Value	Minimum Run	Maximum Value	Maximum Run
O_2 %	14.5	11.9	4-1	15.6	13-1
CO_2 %	6.4	5.2	13-1	8.9	2.0
CO PPM	839	500	26-1	1017	19-1
THC PPM	141	65	26-1	239	19-1
THC Peaks/hr 600	2.69	.23	26-1	7.44	19-1
THC Peaks/hr 300	5.43	1.13	26-1	12.24	19-1
CO Peaks/hr 1500	5.83	1.36	26-1	9.36	19-1

FIGURE 14 - CO AND THC CONCENTRATIONS FOR RUN 10-1

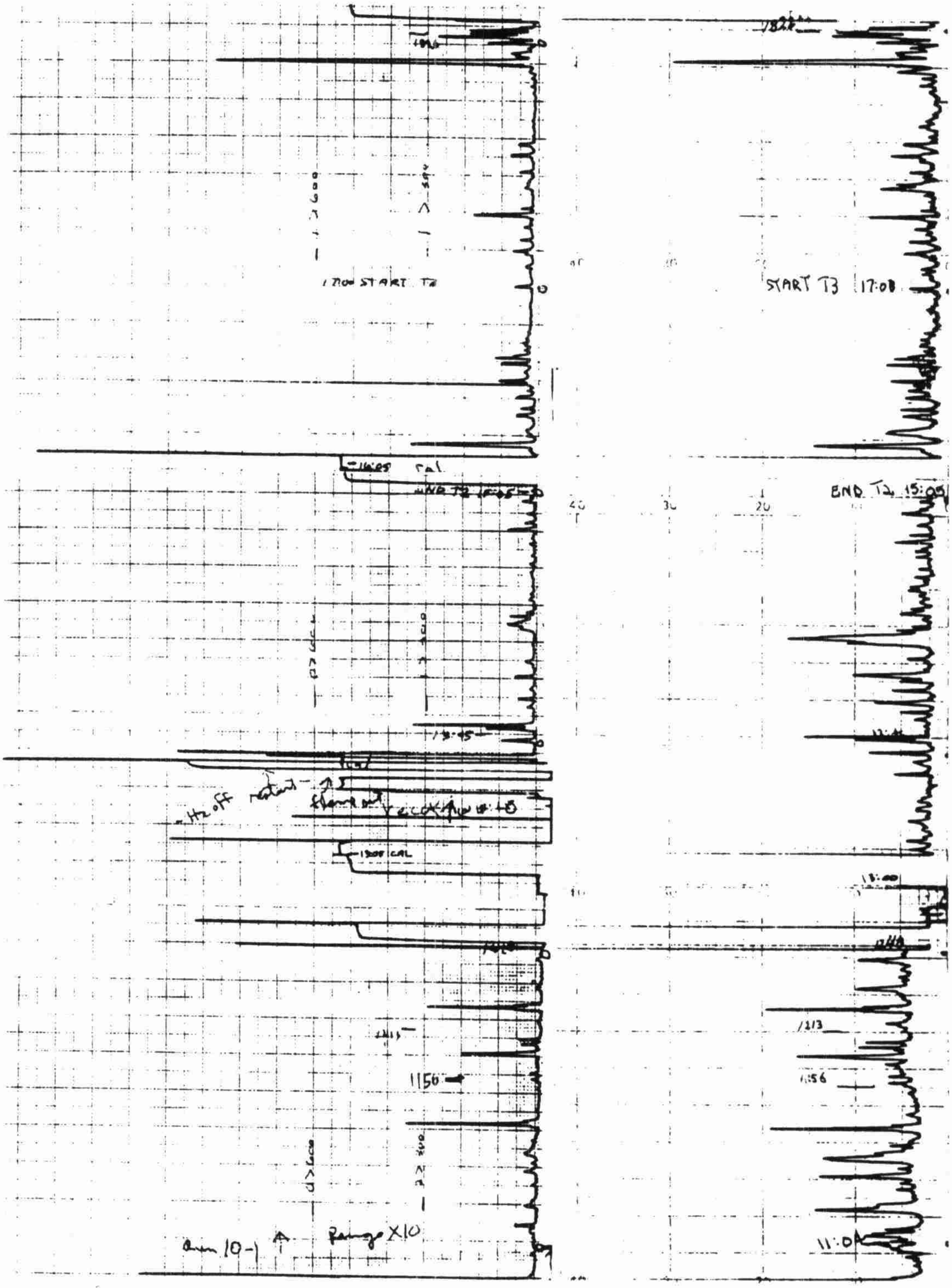
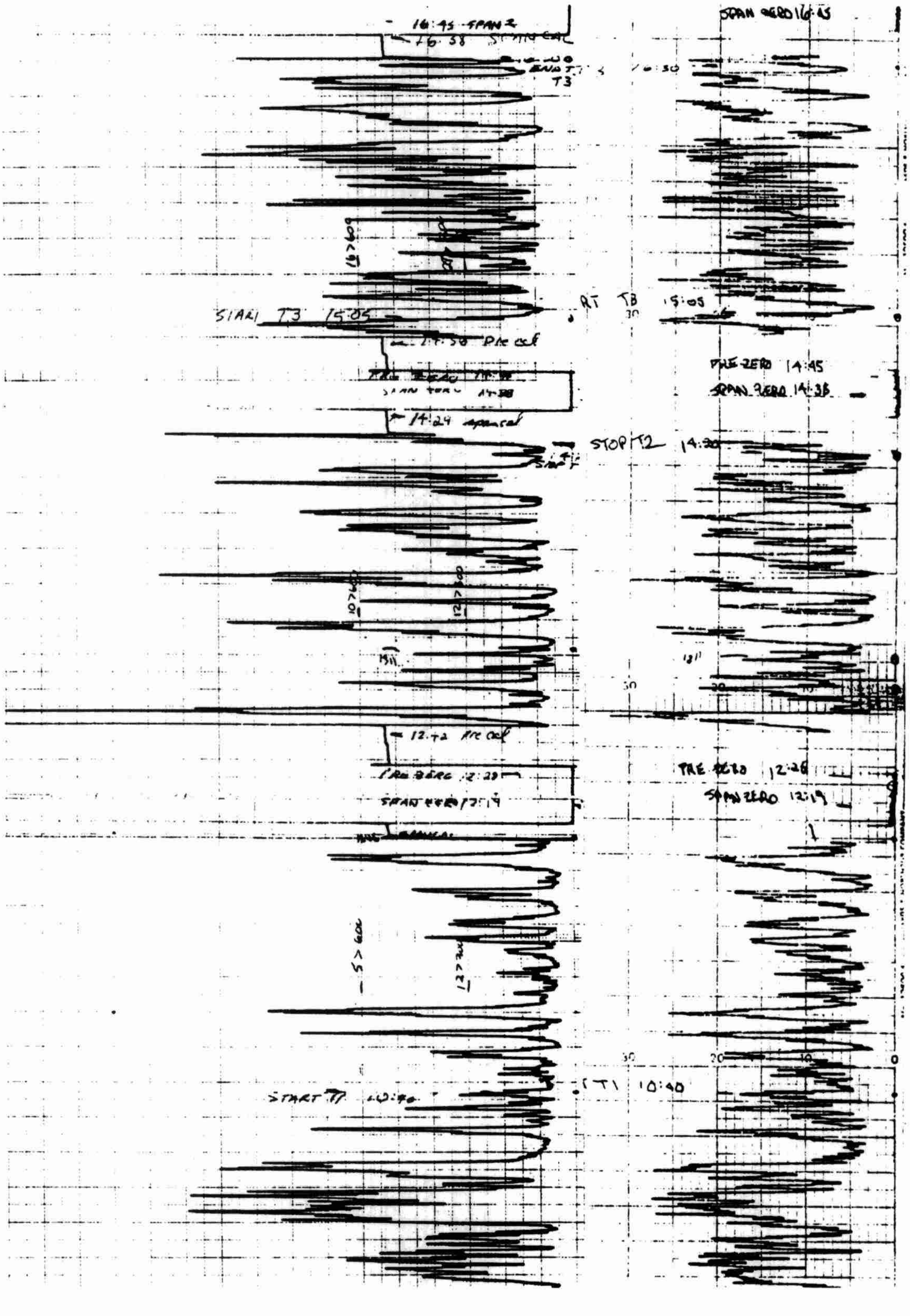


FIGURE 15 - CO AND THC CONCENTRATION FOR RUN 19-1



That is, the presence of piled material on the grates did not always give rise to single or multiple peaks.

Although the CO and THC peaks correspond in time the magnitude of the peaks which appear simultaneously show variations. However, the average levels of CO and THC show reasonable consistency. Figure 16 is a plot of average total hydrocarbon concentrations against average carbon monoxide concentrations. The linear regression line shown on the figure shows a correlation coefficient of 0.81, which suggests that a reasonable linear correlation exists between these variables.

Figure 17 shows plots of average CO and THC concentration against top temperature for the diagnostic tests. Basic theory would suggest that increases in top temperature would lead to decreases in both CO levels and THC levels. While points on this figure show a downward trend, and some narrowing of the range at higher top temperatures, the scatter of the data shows that other factors also affect the levels. This figure also shows the very clear differentiation in CO and THC levels resulting from the low load tests, with lower top temperatures, and high load tests with increased top temperatures. The low load values are higher, and show a broader scatter.

Figure 18 shows plots of average CO and THC against overfire air port flow volume. The overfire air flow, estimated from the static pressure at each overfire air plenum, has been normalized to the diagnostic test where the overfire air port use was highest. Thus 0% on the x-axis corresponds to no overfire air port flow, and 100% represents the highest flow achieved in the tests. The CO values show a consistent downward trend for both low load and high load tests, although the rate of decline for the high load tests appears smaller than for the low load tests. . The THC values for the low load tests show a significant decline with OF air use whereas those for high load tests show little or no trend. The data for CO peak frequency above 1500 ppm and THC peak frequency above 600 ppm against overfire air use show the same general trends with considerable scatter.

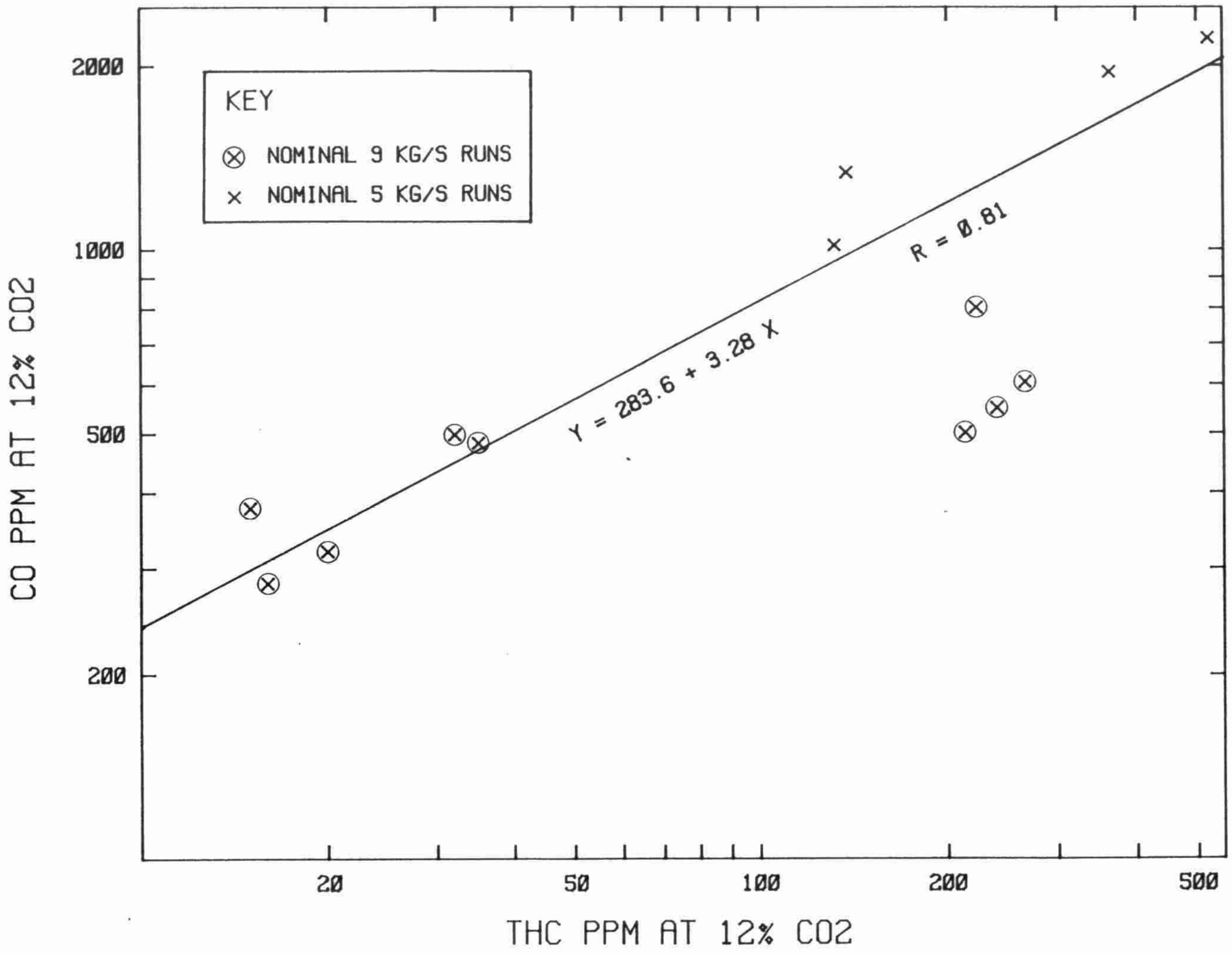


FIGURE 16 - CO CONCENTRATION AND THC CONCENTRATION

FIGURE 17 - CO AND THC CONCENTRATION vs. TOP TEMPERATURE

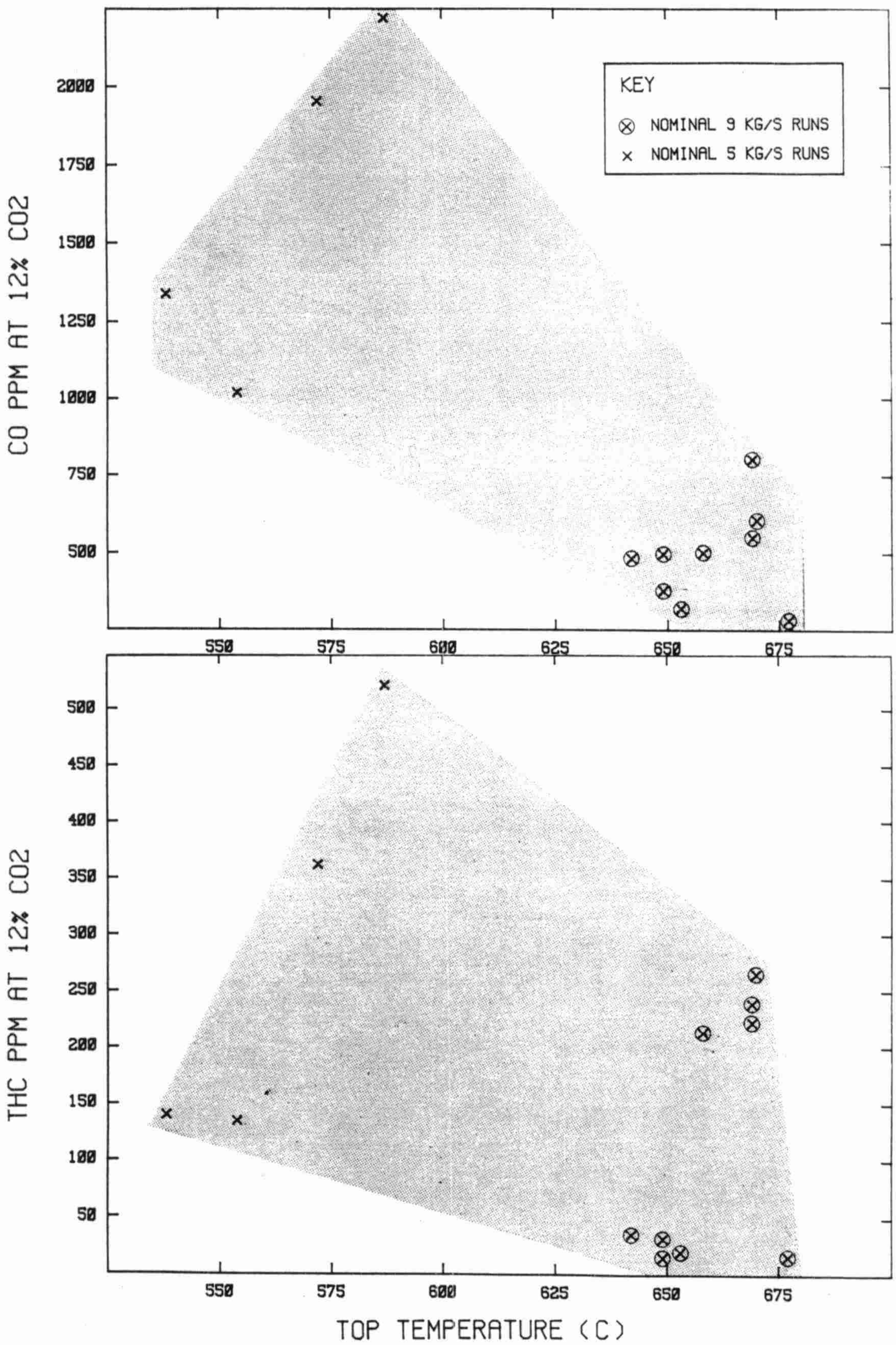


FIGURE 18 - CO AND THC CONCENTRATION vs. OF PORT VOLUME

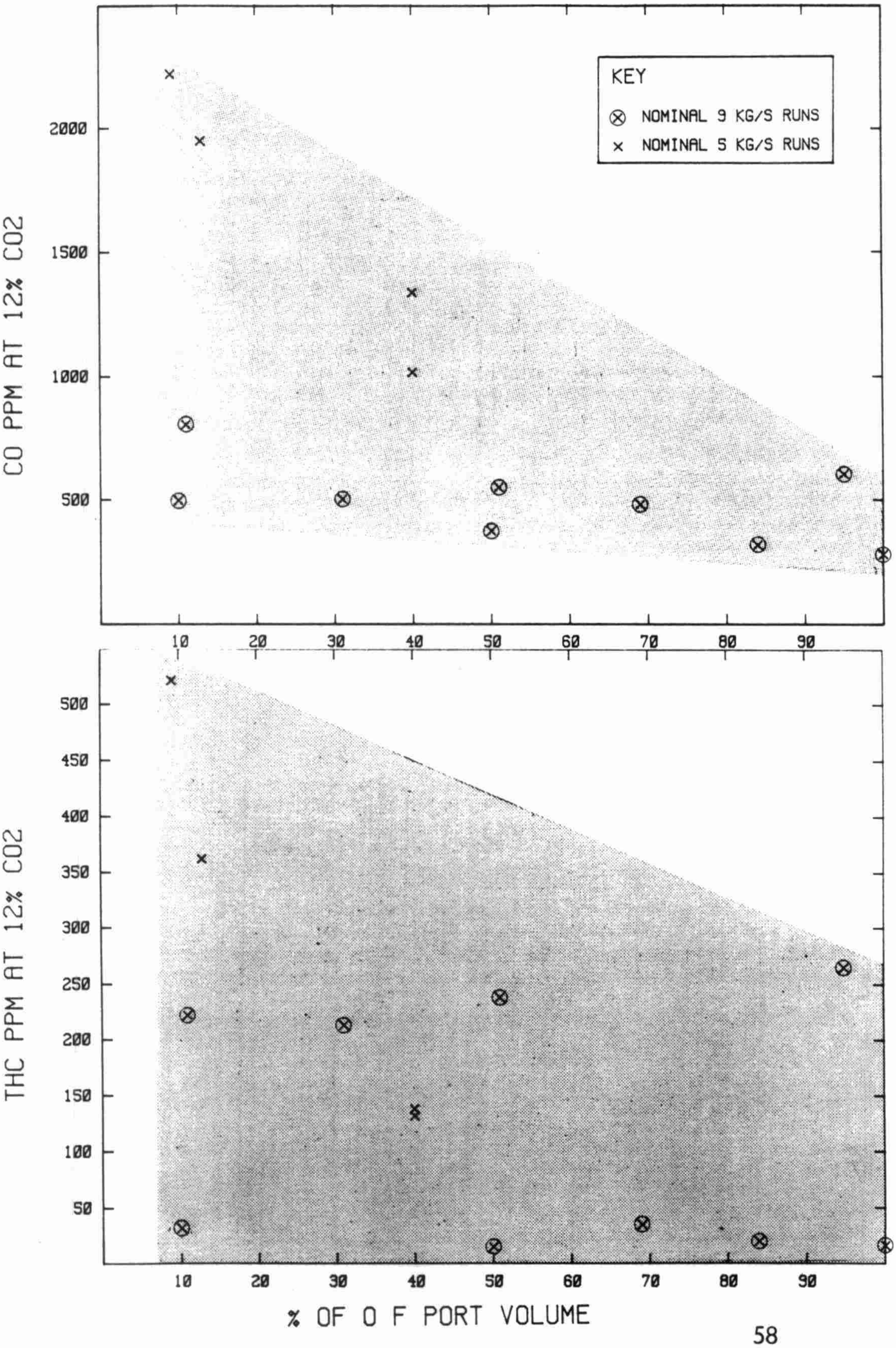


Figure 19 shows plots of average THC and CO concentration against total air for the diagnostic tests. In both cases there is the expected general trend toward higher values as total air increases, although there is considerable scatter. The data for the frequency of THC peaks and CO ppm show the same general trend, with considerable scatter.

Figure 20 shows plots of average THC and CO against fuel moisture content. These plots suggest a general trend toward higher concentrations as fuel moisture increases.

One potential disadvantage of high overfire air port use would be increased boiler carryover and it's effect on precipitator performance. Figure 21 shows plots of particulate concentration at the exit of the air heater, and the stack emission against overfire air port flow volume. These plots do not indicate either an upward or downward trend over the test range.

5.3.4 Ash

Table 8 shows the laboratory results of moisture content and higher heating value for three reduced grate and precipitator ash samples from tests 10-1 and 19-1. As indicated by the table, the calorific value of the grate ash is low, indicating good burnout. The precipitator ash has a significant and variable higher heating value.

This data and the level of combustibles in the particulate carryover after the air heater indicate incomplete burnout in the gas phase.

FIGURE 19 - CO AND THC CONCENTRATION vs. TOTAL AIR

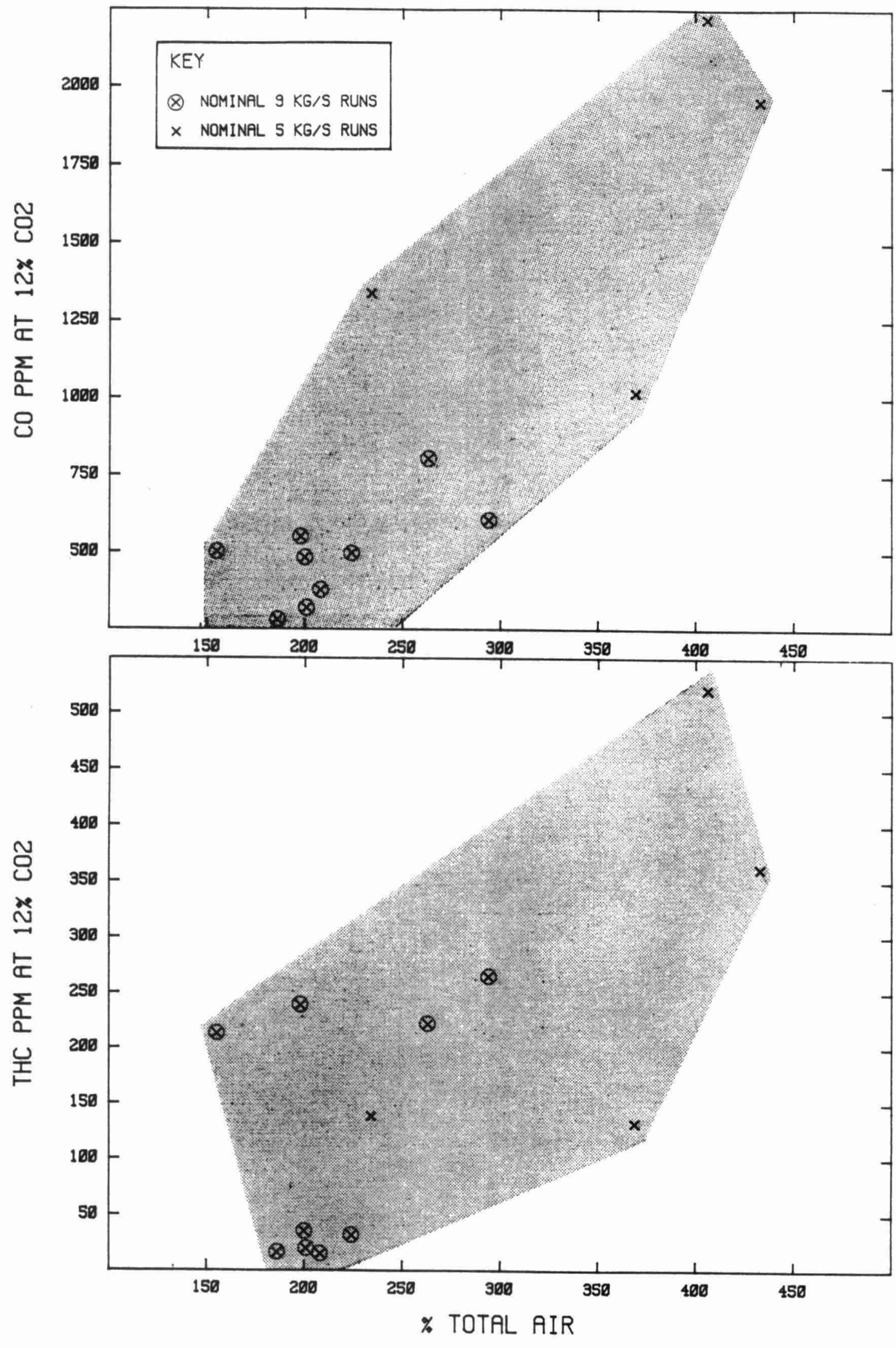


FIGURE 20 - CO AND THC CONCENTRATION vs. AIR DRY MOISTURE IN FUEL

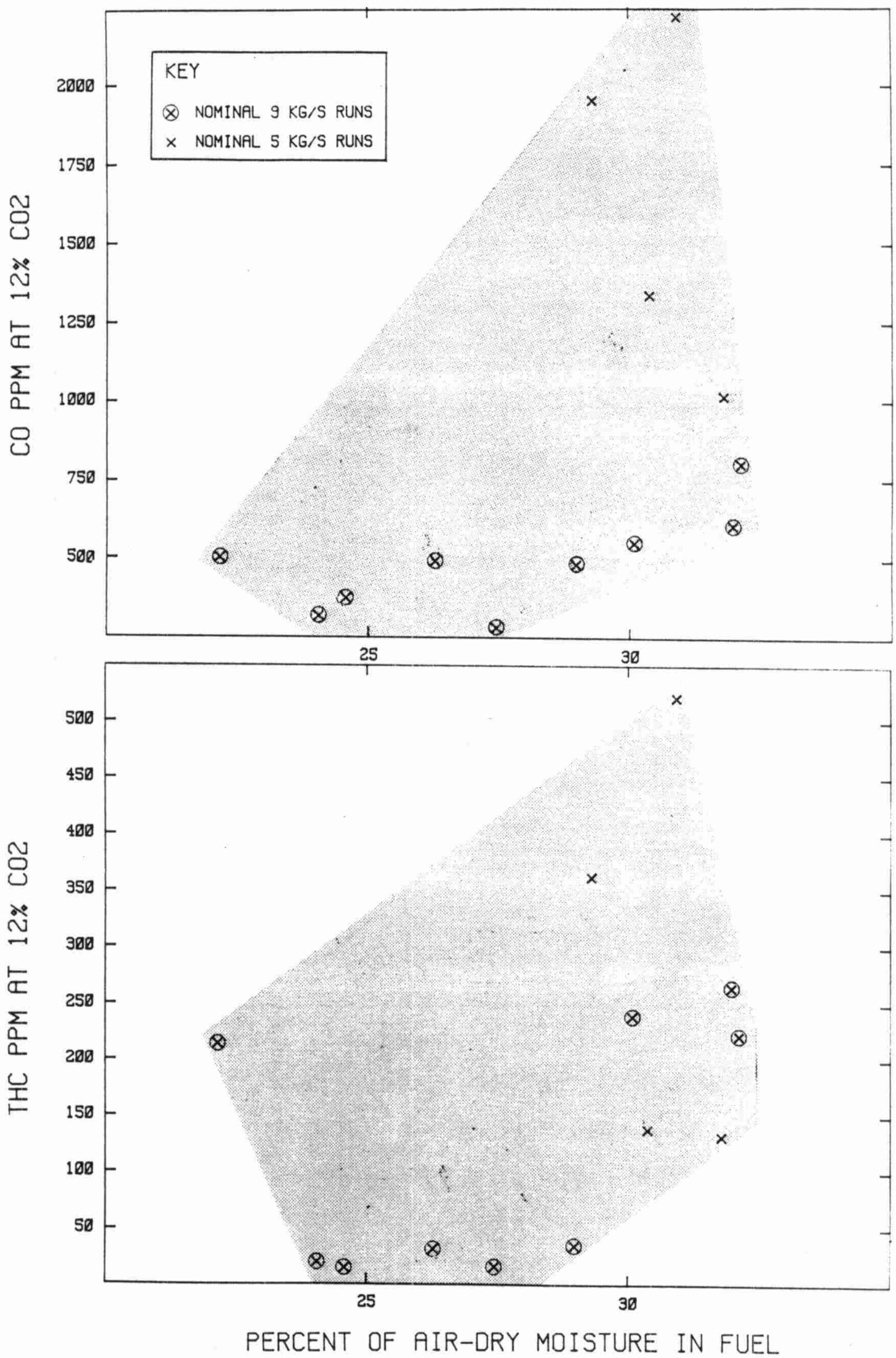


FIGURE 21 - FURNACE EXIT PARTICULATE AND STACK EMISSIONS vs. OF PORT VOLUME

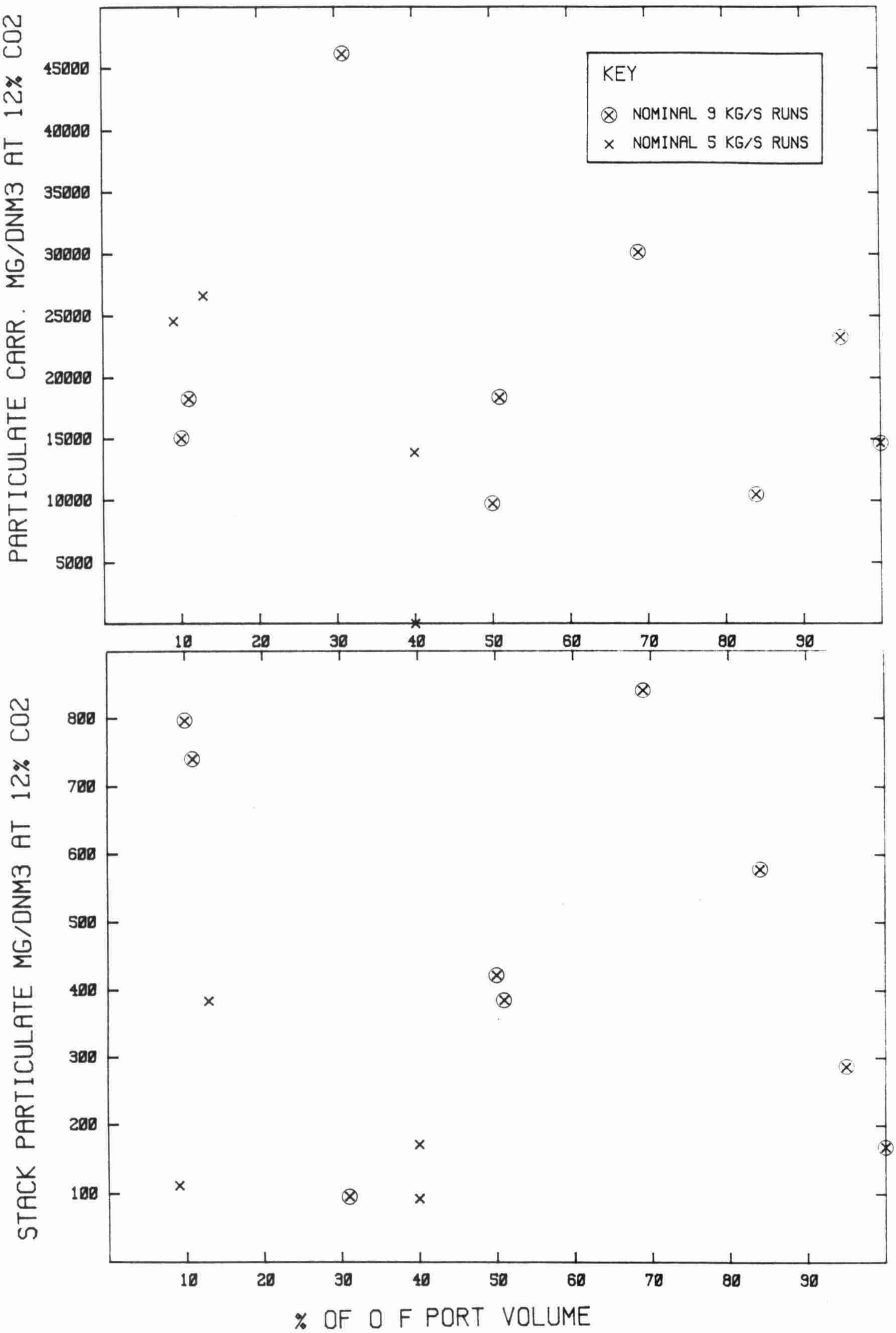


TABLE 8

ASH SAMPLE ANALYSIS

SAMPLE		PRECIPITATOR ASH High Heating Value k Joules/g	(BTU/lb)	Moisture	BOTTOM ASH High Heating Value k Joules/g	(BTU/lb)	Moisture
10-1	T-1	.07	(30)	44.4	.02	(10)	31.8
	T-2	1.32	(570)	58.2	.02	(10)	28.8
	T-3	.02	(10)	56.6	.02	(10)	27.5
Average ±							
Std. Dev.		.47	(203)	53.1	.02	(10)	29.4
		.74	(318)	8.0	.02	(10)	2.2
19-1	T-1	1.63	(700)	54.7	.02	(10)	23.7
	T-2	.84	(360)	51.7	.09	(10)	25.5
	T-3	1.28	(550)	56.9	.02	(10)	30.6
Average ±							
Std. Dev.		1.25	(537)	54.4	.04	(20)	26.6
		.40	(170)	2.6	.04	(17.3)	3.6

Tables 9 and 10 show the results of the dioxin, furan and precursor analyses of the bottom ash samples and precipitator ash samples as reported by Ontario Research Foundation. Levels for the grate ash samples are generally near the respective detectability levels but show considerable variations. Levels for the precipitator ash are significantly higher, but also show considerable variations.

Table 11 shows an overall mass balance for the dioxins, furans and precursors for the low and high load tests. These mass balances were based on:

- the average concentrations for each contaminant in the fuel, grate ash and precipitator ash (ug/g),
- the mass emission rate in the stack (ug/s) from the ORF data,

the averaged grate and precipitator ash rates measured,

and - a calculated full rate based on the ash contents from Runs 10-1 and 19-1 and the total averaged grate ash, precipitator ash and stack particulate emission rate.

In view of the very limited number of samples analyzed, these results can only be expected to show order of magnitude trends. The values shown in the table suggest that a very small proportion of the mass of these contaminants is found in the grate ash. In several cases, a significant proportion is indicated in the precipitator ash, but the predominant quantities are contained in the flue gas. The ratios of the amounts entering to the amount leaving suggest little variation for dioxins and chlorophenols, and a very substantial decrease in PCB's. The ratios also suggest substantial increases in furans and chlorobenzenes.

5.3.5 ASME Combustion and Boiler Efficiency Results

The ultimate analysis, HHV and other directly measured data for tests 10-1 and 19-1 were used to determine incineration efficiency using a heat loss method

TABLE 9

DIOXIN, FURAN AND PRECURSOR CONCENTRATIONS IN GRATE ASH SAMPLES

RUN	DIOXINS ng/g	FURANS ng/g	CHLOROBENZENES ng/g	PCB's ng/g	CHLOROPHENOLS ng/g
1	0.6	1.1	1.1	2.0	3.0
4	ND	ND	ND	0.5	ND
5	ND	ND	ND	0.3	3.0
6	NA	NA	ND	0.4	ND
7	ND	1.3	0.2	0.3	ND
8	0.7	ND	ND	0.2	1.0
9	0.4	0.4	ND	ND	3.0
10	0.1	ND	ND	ND	1.5
11	0.1	ND	ND	0.4	6.0
12	0.5	ND	0.8	0.2	5.0
13	0.1	ND	ND	0.3	10.0
14	3.3	3.9	ND	ND	2.0
15	0.4	ND	ND	0.4	4.0
Average	0.5	0.6	0.2	0.4	3.0

ND = None Detected
NA = Not Analyzed

TABLE 10

DIOXIN, FURAN AND PRECURSOR CONCENTRATIONS IN PRECIPITATOR ASH SAMPLES

RUN	DIOXINS ng/g	FURANS ng/g	CHLOROBENZENES ng/g	PCB's ng/g	CHLOROPHENOLS ng/g
1	32.5	89	20.0	4.0	ND
4	94.2	105	4.4	3.4	240
5	33.3	70	2.4	2.8	26
6	11.2	31	2.4	0.4	15
7	14.4	54	2.6	0.9	22
8	9.5	49	4.4	2.2	16
9	7.7	24	3.2	0.4	ND
10	17.3	29	1.6	0.9	52
11	9.6	36	1.0	ND	17
12	16.9	22	2.0	ND	26
13	10.8	33	1.1	1.0	30
14	35.3	41	3.0	0.4	100
15	6.2	23	6.2	1.7	20
Average	23.0	46.	4.2	1.4	43

ND = None Detected

TABLE 11

SYSTEM MASS BALANCE

STEAMING RATE (5 kg/s)		DIOXINS	FURANS	CHLOROBENZENES	PCB'S	CHLOROPHENOLS
				CONTAMINANTS		
Entering Boiler: Fuel		38.10	4.43	24.24	220.30	1,002.98
Exiting Boiler:						
Grate Ash	(ug/s)	.26	.31	.12	.22	1.57
Precip. Ash	(ug/s)	3.25	6.58	.59	.20	6.07
Flue Gas	(ug/s)	37.37	62.48	421.55	5.87	1,100.26
Total Exiting	(ug/s)	40.88	69.37	422.26	6.29	1,107.90
Ratio of Exiting/Entering		1.1	15.7	17.4	.03	1.1
STEAMING RATE (9 kg/s)						
Entering Boiler: Fuel		47.47	5.52	30.21	274.53	1,244.91
Exiting Boiler:						
Grate Ash	(ug/s)	.30	.34	.14	.24	1.77
Precip. Ash	(ug/s)	5.54	11.23	1.01	.34	10.36
Flue Gas	(ug/s)	47.93	120.35	839.76	8.52	869.94
Total Exiting	(ug/s)	53.77	131.92	840.91	9.10	882.07
Ratio of Exiting/Entering		1.1	23.9	27.8	.03	.71

developed from ASME PTC 33-1978, Large Incinerators. This data was also used to determine boiler thermal efficiency using the Abbreviated Heat Loss Method as described in ASME PTC 4.1-1974, Steam Generating Units.

Results are as follows:

For Run 10-1	Incinerator Efficiency 99.69%
	Boiler Thermal Efficiency 55.7%
For Run 19-1	Incineration Efficiency 99.15%
	Boiler Thermal Efficiency 42.6%

5.3.6 Stack Emissions

The results of the dioxin and furan analysis for each diagnostic test are shown in Appendix II. These results show a considerable range in values, with dioxin concentrations normalized to 12% CO_2 varying from 1.3 ug/Nm^3 to 11.1 ug/m^3 and nomalized furan concentrations varying from 3.7 ug/m^3 to 12.5 ug/m^3, which indicates that changes in parameters for the diagnostic tests were sufficient to affect the emission concentrations of these compounds. However, some caution must be used in the interpretation of this data, since the sampling durations were of minimal length, and protocol for sampling and analysis is in the developmental stages and is very complex. As indicated by Ontario Research Foundation the confidence limits for dioxin and furan, based on the phases of the protocol for which replicate analyses are available, are about 28% and 21% respectively. Recent research conducted on a similar protocol for dioxin sampling and analysis by Battelle Columbus Laboratories Reference: (Symposium on Land, Disposal, Incineration and Treatment of Hazardous Waste, Ft Mitchell KY, March 1983), indicates that the sample to sample variability could exceed 50%.

Although attempts were made to correlate dioxin and furan concentrations to an extensive series of parameters measured, the results were not definitive. The plotted results and a discussion of four of these efforts follows.

Figure 22 shows plots of dioxin and furan concentrations against furnace top temperature. Although there was no identified trend in the dioxin data, there appears to be a very weak trend toward increasing furan concentrations with increasing top temperature.

Figure 23 shows dioxin and furan concentrations against overfire air port flow. Once again, there was no identified trend in the dioxin data, but there appears to be a weak trend toward increasing furan concentrations at increased overfire air port flow.

Figure 24 shows plots of dioxin and furan concentrations against total air. In this case there is no apparent furan trend, but appears to be a weak trend toward higher concentrations and a broader range of concentrations of dioxins as the total air increases.

Figure 25 shows dioxin and furan concentrations against total hydrocarbon levels. In both cases there is a weak trend toward higher values as hydrocarbon concentrations increase, suggesting some support for the premise that dioxin, furan and hydrocarbon concentrations are related, although other parameters are obviously important.

Particulate concentrations at the stack against gas flow and temperature entering the precipitator are shown in Figure 26. The expected trends of greater emission variability with increased gas flowrate and temperature are evident, but other parameters are obviously important.

FIGURE 22 - FURAN AND DIOXIN CONCENTRATION vs. TOP TEMPERATURE

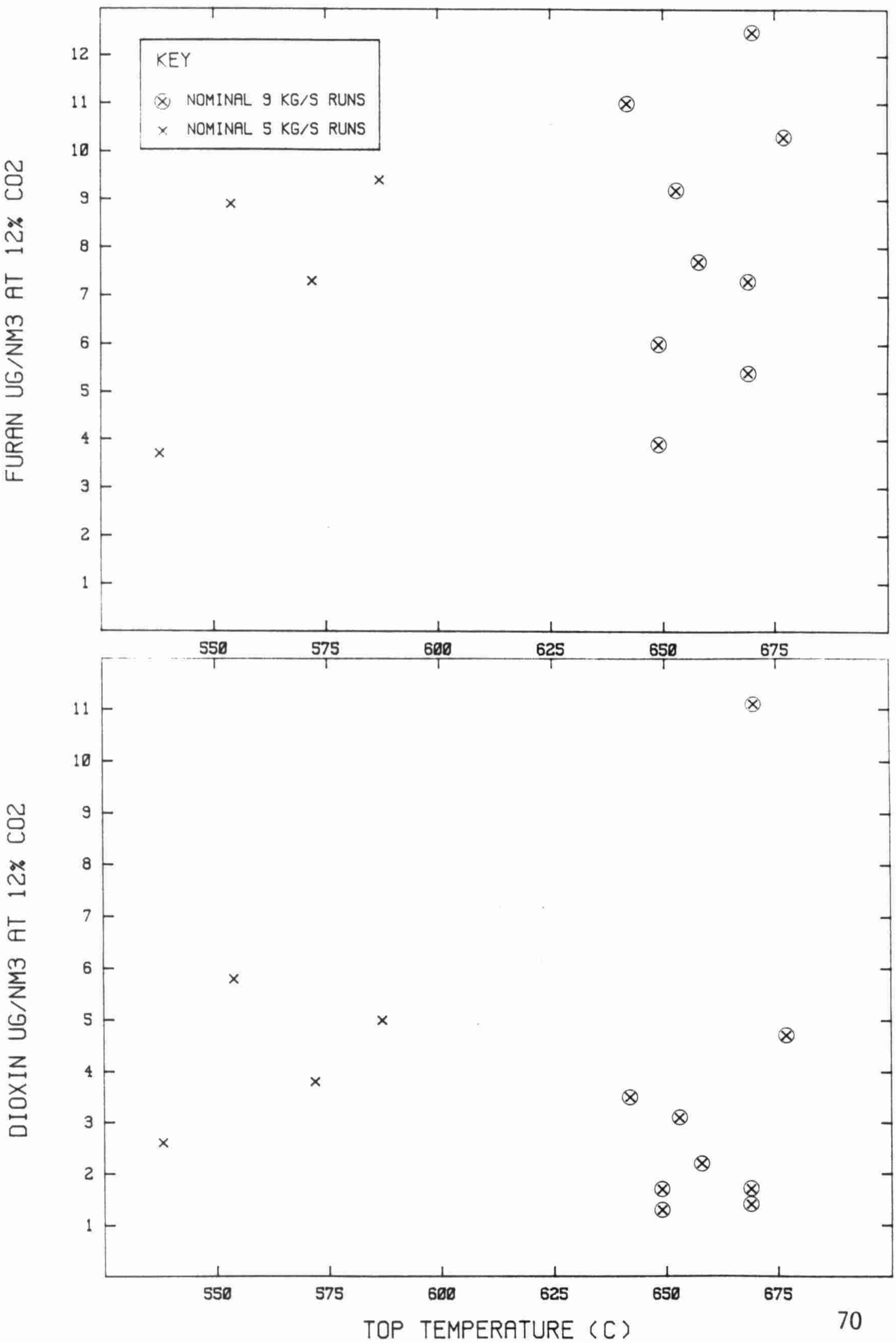


FIGURE 23 - FURAN AND DIOXIN CONCENTRATIONS vs. OF PORT VOLUME

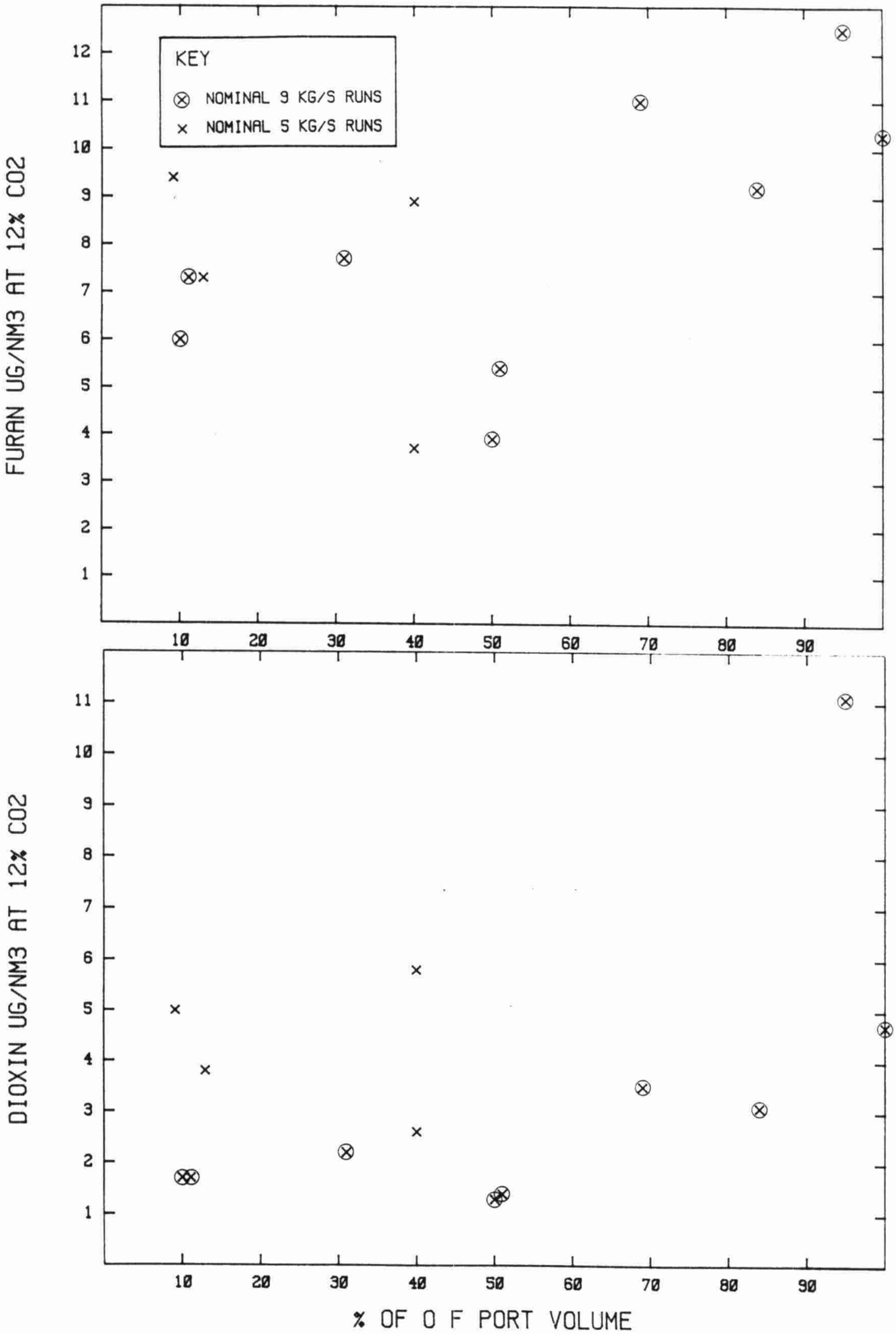


FIGURE 24 - FURAN AND DIOXIN CONCENTRATIOINS vs. TOTAL AIR

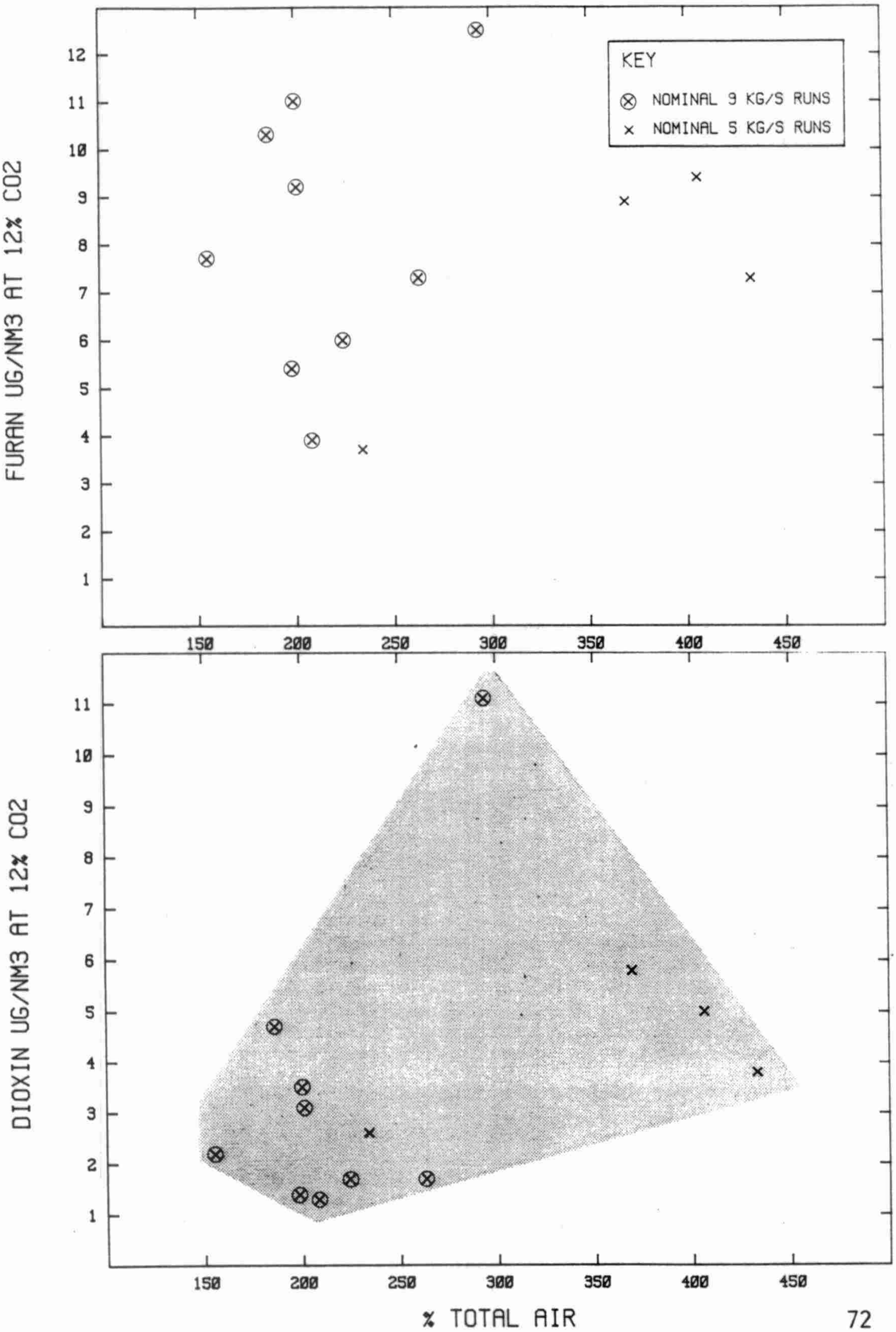


FIGURE 25 - FURAN AND DIOXIN CONCENTRATIONS vs. THC CONCENTRATIONS

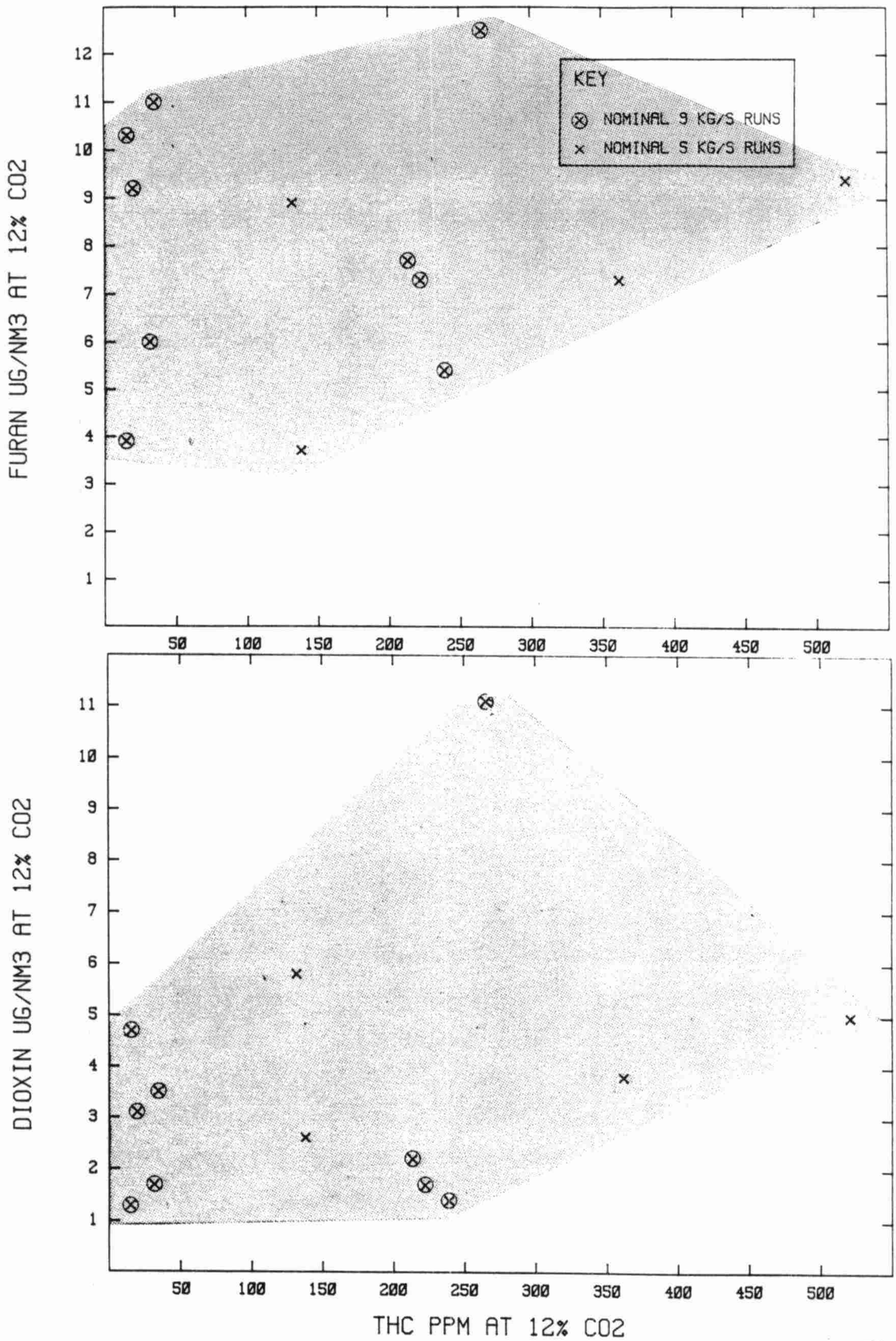
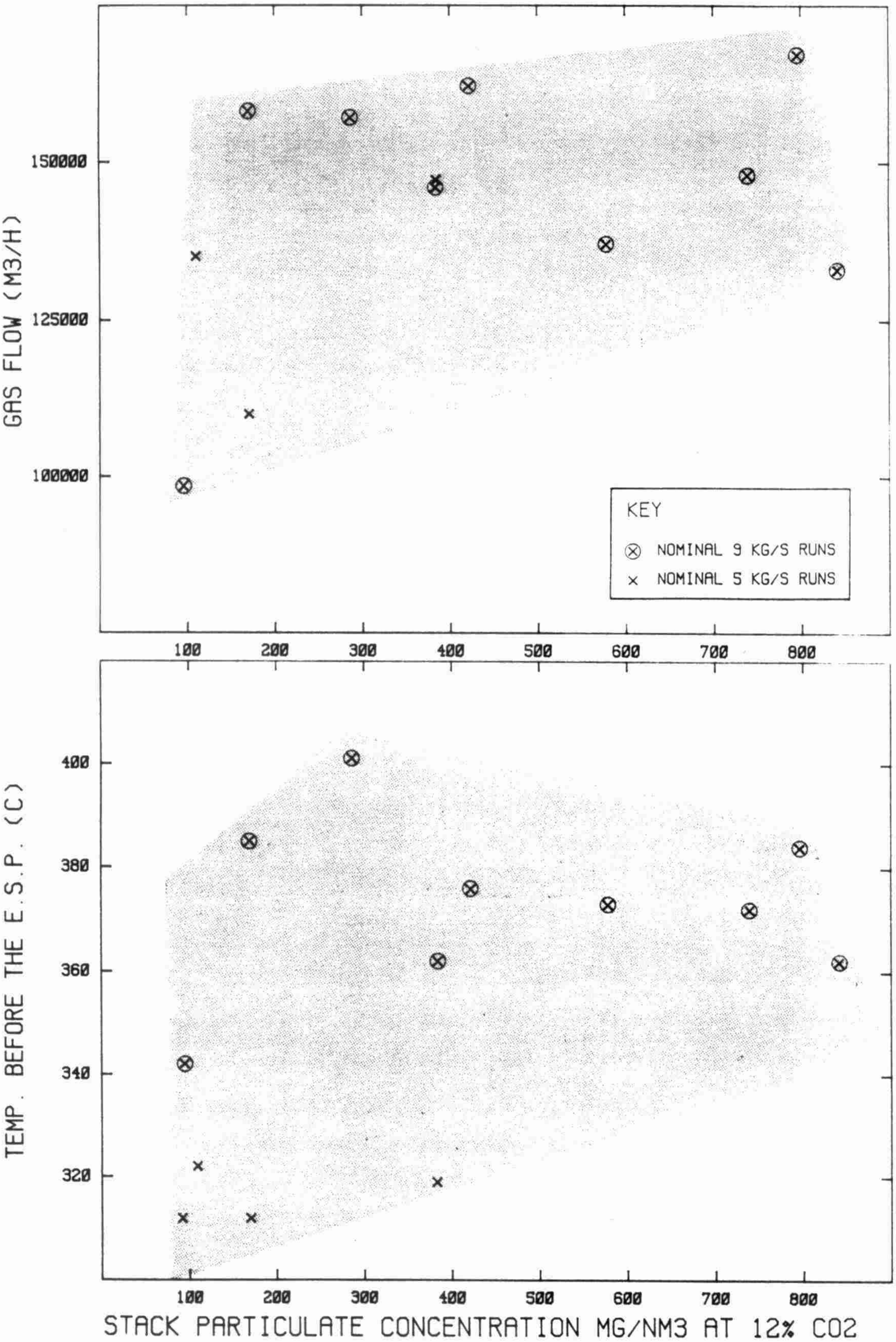


FIGURE 26 - GAS FLOW vs. STACK PARTICULATE CONCENTRATION



Continuous measurements of SO_2 through the diagnostic tests show an average range of 13 ppm to 57 ppm. Continuous NOx monitoring through tests 21-1, 4-1 and 5-1 showed levels in the range of 83 ppm to 123 ppm. Analyses of the moisture determination impinger catches for tests 24-1, 25-1 and 26-1 showed HCl concentrations ranging from 98 to 1030 mg/Nm^3.

6.0 SUMMARY COMMENTS

6.1 Equipment and Maintenance

6.1.1 The existing feed control system with a minimum 2.5 minute lag from the control point to the boiler feed chutes severly limits the operator's capability of responding to changes in the combustion performance of the furnace. A significant improvement would result from incorporating a fuel recycle system and individual direct fuel controls to each unit.

6.1.2 The maintenance of consistent steam pressure and flow conditions is beyond the capability of the current system. In addition, the use of top temperature as the automatic feed control variable may not lead to optimal performance, and should be reviewed. Many of the existing pneumatic control systems, particulately those for fan drives, were sluggish and caused operating problems. An overall review and upgrading of process control, including solid state micro-processing, would be justified in terms of improved consistency of operation.

6.1.3 The existing feed system uses a very significant amount of conveying air, and this air addition causes flow chanelling in the furnace. In addition, the current design allows a very significant amount of induced air to pass into the furnace through the chute. Both of these flows contribute to the high total air levels observed.

6.1.4 The existing rear grate seals and blockage of holes in the grates result in maldistribution of combustion air into the lower furnace and to the bed on the grates respectively. This necessitates high rate of combustion air and contributes to the high total air flows. Effective rear seals and more frequent cleaning of the grates would result in lower undergrate air useage and reduced clinkering.

6.1.5 The usefulness of the observation viewports was proven during the study. These should be retained and possibly supplemented or relocated to the other side of the boiler for operating convenience. Monitoring of flows through the feed chutes and overfire air plenums also proved useful and should be incorporated in a permanent fashion.

6.1.6 The existing soot blowers should be used to ascertain their effect in reducing the furnace exit temperature for improved precipitator performance. Additional soot blowers or an alternative method should be considered to reduce buildup in the precipitator inlet flue and provide better precipitator distribution.

6.1.7 The general condition and maintenance of the equipment during the testing program caused a number of delays and was not conducive to maintaining consistently good furnace performance.

6.2 Effect of Operating Parameters on Combustion

6.2.1 The broad range of fuel properties indicated by data obtained during the test program was within the expected range for municipal refuse. Fuel preparation and shredding equipment which can minimize the impact of fuel property changes, and control systems which can monitor the effects of residual changes, are required by the operators to achieve consistently good combustion performance.

6.2.2 Average and peak concentrations of total hydrocarbons and carbon monoxide appear to be correlated and tend to decrease with increased top temperature, overfire air port use, and low total air levels. Continuous monitoring of oxygen and carbon monoxide (or total hydrocarbons if reliable instrumentation can be acquired) would contribute to good combustion performance.

6.2.3 The maximum average furnace top temperatures achieved during the program was 677°C, and levels for several tests were well below 600°C. Modifications to the undergrate and overfire air distribution systems, combined with an on-line oxygen monitor would make significant reductions in total air and significant increases in top temperature possible, and would lead to improved combustion performance.

6.3 Operating Conditions and Emissions

6.3.1 Emissions of hydrocarbons exceeded the Ontario Ministry of the Environment incineration criterion of 100 ppm during most of the combustion runs and diagnostic tests. However, values below 50 ppm were maintained during several diagnostic runs, which indicates that with consistent and improved performance the incineration criterion can be met.

6.3.2 A direct, simple correlation between boiler operating parameters and dioxin and furan concentration was not identified.

6.3.3 The lack of positive trends between dioxin and furan concentrations and parameters examined, including furnace top temperature, overfire air port flow, total air, THC and CO concentrations, suggests that none of these parameters can be used as the single parameter to minimize dioxin and furan emissions.

6.3.4 Further detailed examination of the samples and data obtained during the program would be useful in examining the obviously complex correlation between operating parameters and the emission of dioxins, furans, and other chlorinated organics.

6.3.5 The interpretation of the results of definitive dioxin stack tests would be simplified if modifications to improve combustion performance, stability and consistency are made before the tests are undertaken.

TABLE 6
SUMMARY OF FURNACE TEMPERATURE DATA

NOMINAL STEAM FLOW 9 kg/sec (9 runs)

	Overall Average	Minimum Value	Minimum Run	Maximum Value	Maximum Run
Air Heater Exit					
Gas Temp °C	372	342	21-1	397	25-1
Top Temp °C	659	642	5-1	677	6-1
Upper Furnace					
Temperature °C	652	599	5-1	741	17-1
Lower Furnace					
Temperature °C	751	713	21-1	791	12-1
Grate Temp °C	245	231	12-1	264	25-1
Total Air %	214	155	21-1	294	25-1
Average Steam Flow kg/s	8.51	8.03	5-1	9.21	6-1

NOMINAL STEAM FLOW 5 kg/sec (4 runs)

	Overall Average	Minimum Value	Minimum Run	Maximum Value	Maximum Run
Air Heater Exit					
Gas Temp °C	317	312	4-1/26-1	323	19-1
Top Temp °C	563	538	4-1	587	19-1
Upper Furnace					
Temperature °C	576	508	4-1	636	19-1
Lower Furnace					
Temperature °C	604	547	26-1	659	13-1
Grate Temp °C	225	207	13-1	247	26-1
Total Air %	360	234	4-1	433	13-1
Average Steam Flow kg/s	5.12	4.86	4-1	5.48	19-1

TABLE 7
SUMMARY OF CONTINUOUS GAS ANALYSIS

NOMINAL STEAM FLOW 8.82 kg/sec (9 runs)

	Average Value	Minimum Value	Minimum Run	Maximum Value	Maximum Run
O_2 %	10.9	7.4	21-1	13.7	25-1
CO_2 %	9.7	7.1	25-1	12.4	21-1
CO PPM	383	252	6-1	518	21-1
THC PPM	90	12	11-1	220	21-1
THC Peaks/hr 600	2.59	.16	10-1	6.77	21-1
THC Peaks/hr 300	3.89	.24	11-1	10.65	21-1
CO Peaks/hr 1500	2.70	.47	11-1	7.26	21-1

NOMINAL STEAM FLOW 5.04 kg/sec (4 runs)

	Average Value	Minimum Value	Minimum Run	Maximum Value	Maximum Run
O_2 %	14.5	11.9	4-1	15.6	13-1
CO_2 %	6.4	5.2	13-1	8.9	2.0
CO PPM	839	500	26-1	1017	19-1
THC PPM	141	65	26-1	239	19-1
THC Peaks/hr 600	2.69	.23	26-1	7.44	19-1
THC Peaks/hr 300	5.43	1.13	26-1	12.24	19-1
CO Peaks/hr 1500	5.83	1.36	26-1	9.36	19-1

FIGURE 14 - CO AND THC CONCENTRATIONS FOR RUN 10-1

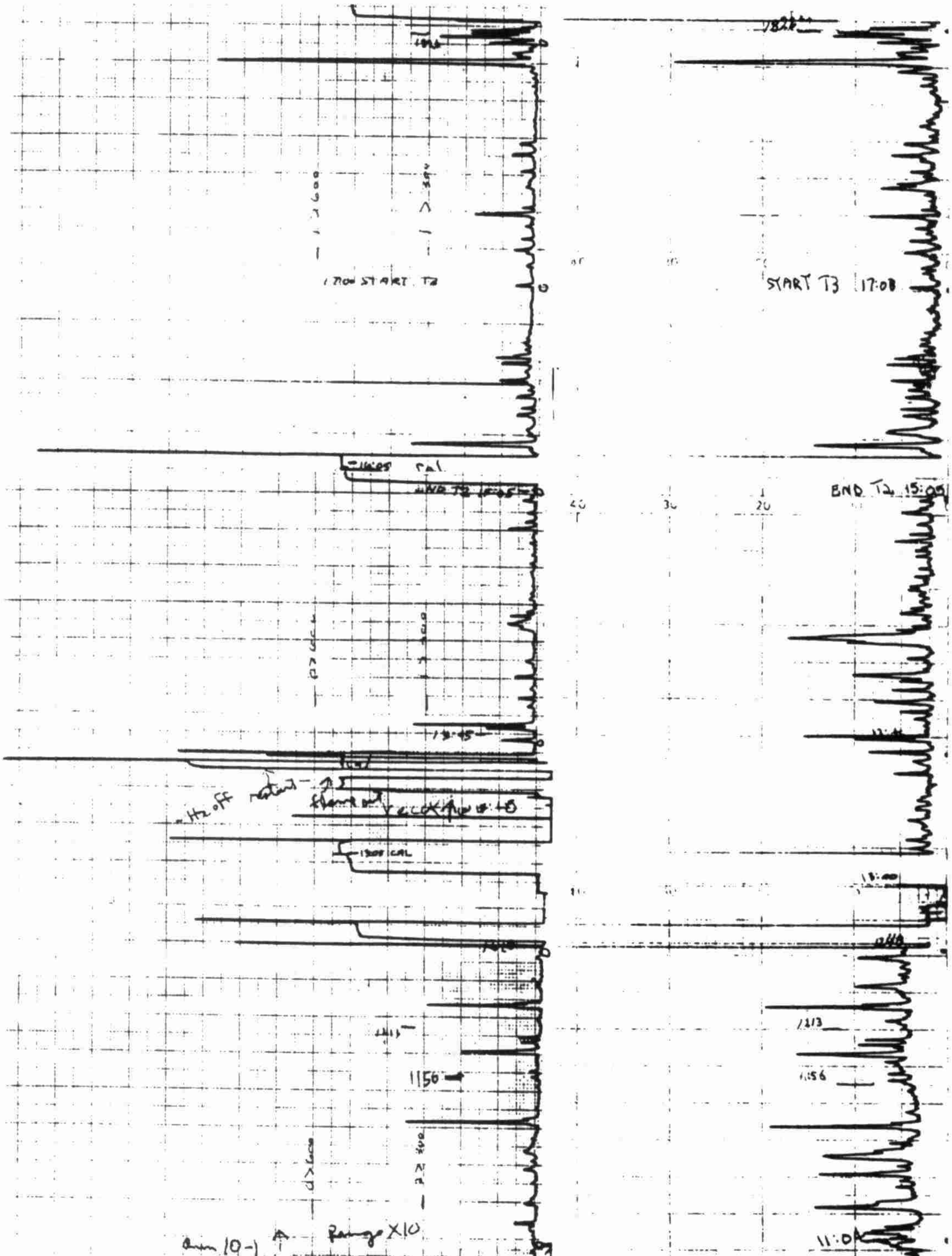
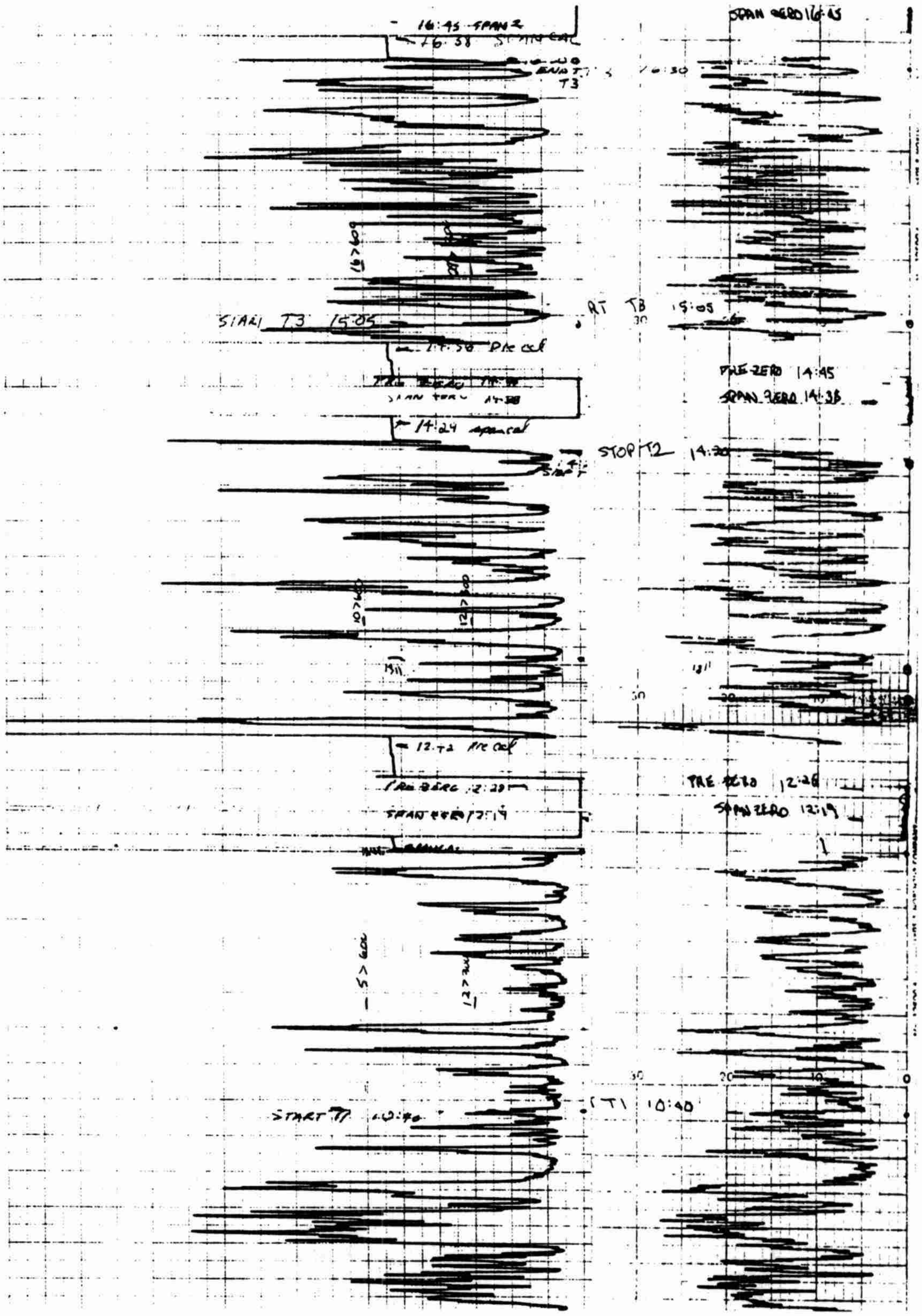


FIGURE 15 - CO AND THC CONCENTRATION FOR RUN 19-1



That is, the presence of piled material on the grates did not always give rise to single or multiple peaks.

Although the CO and THC peaks correspond in time the magnitude of the peaks which appear simultaneously show variations. However, the average levels of CO and THC show reasonable consistency. Figure 16 is a plot of average total hydrocarbon concentrations against average carbon monoxide concentrations. The linear regression line shown on the figure shows a correlation coefficient of 0.81, which suggests that a reasonable linear correlation exists between these variables.

Figure 17 shows plots of average CO and THC concentration against top temperature for the diagnostic tests. Basic theory would suggest that increases in top temperature would lead to decreases in both CO levels and THC levels. While points on this figure show a downward trend, and some narrowing of the range at higher top temperatures, the scatter of the data shows that other factors also affect the levels. This figure also shows the very clear differentiation in CO and THC levels resulting from the low load tests, with lower top temperatures, and high load tests with increased top temperatures. The low load values are higher, and show a broader scatter.

Figure 18 shows plots of average CO and THC against overfire air port flow volume. The overfire air flow, estimated from the static pressure at each overfire air plenum, has been normalized to the diagnostic test where the overfire air port use was highest. Thus 0% on the x-axis corresponds to no overfire air port flow, and 100% represents the highest flow achieved in the tests. The CO values show a consistent downward trend for both low load and high load tests, although the rate of decline for the high load tests appears smaller than for the low load tests. . The THC values for the low load tests show a significant decline with OF air use whereas those for high load tests show little or no trend. The data for CO peak frequency above 1500 ppm and THC peak frequency above 600 ppm against overfire air use show the same general trends with considerable scatter.

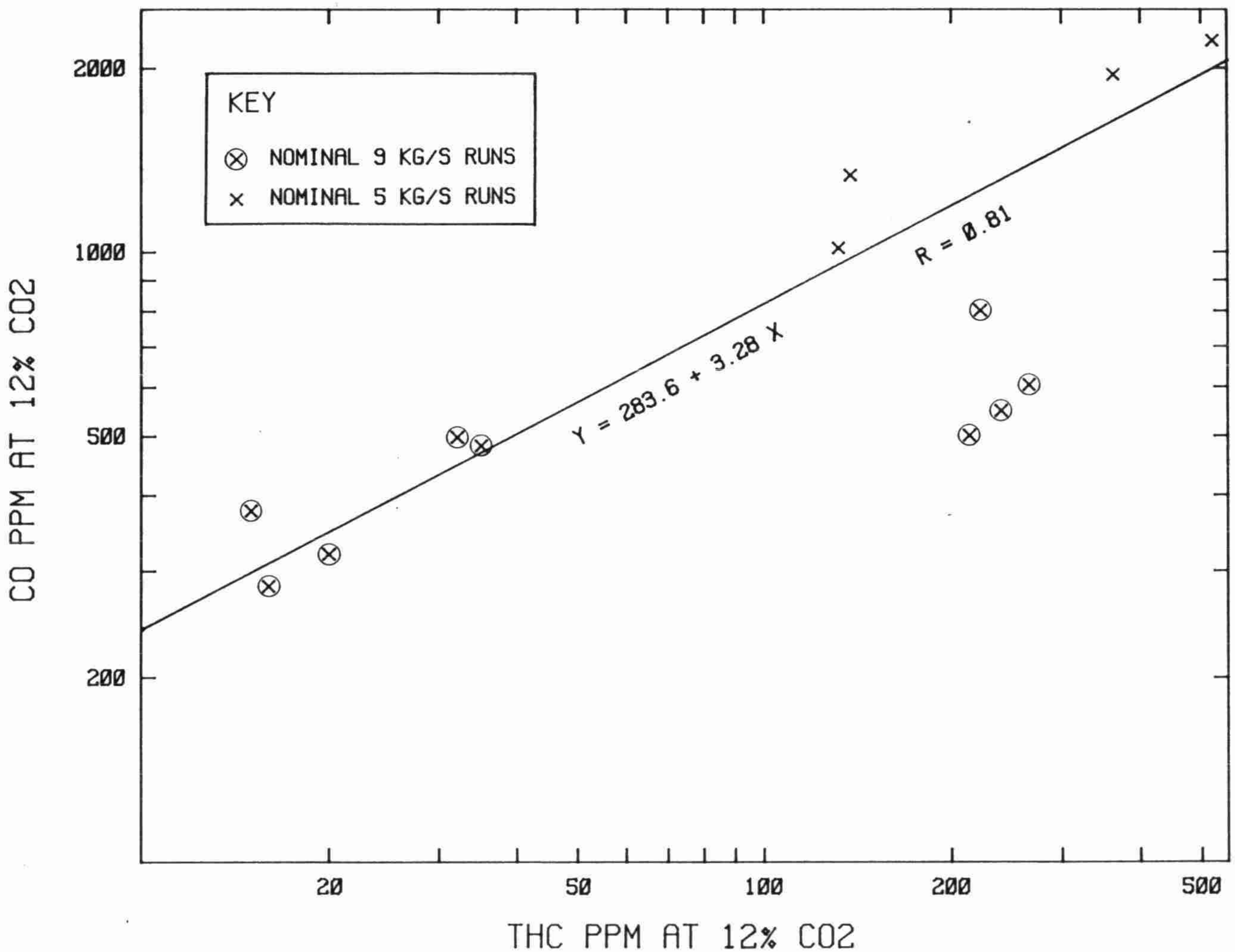


FIGURE 16 - CO CONCENTRATION AND THC CONCENTRATION

FIGURE 17 - CO AND THC CONCENTRATION vs. TOP TEMPERATURE

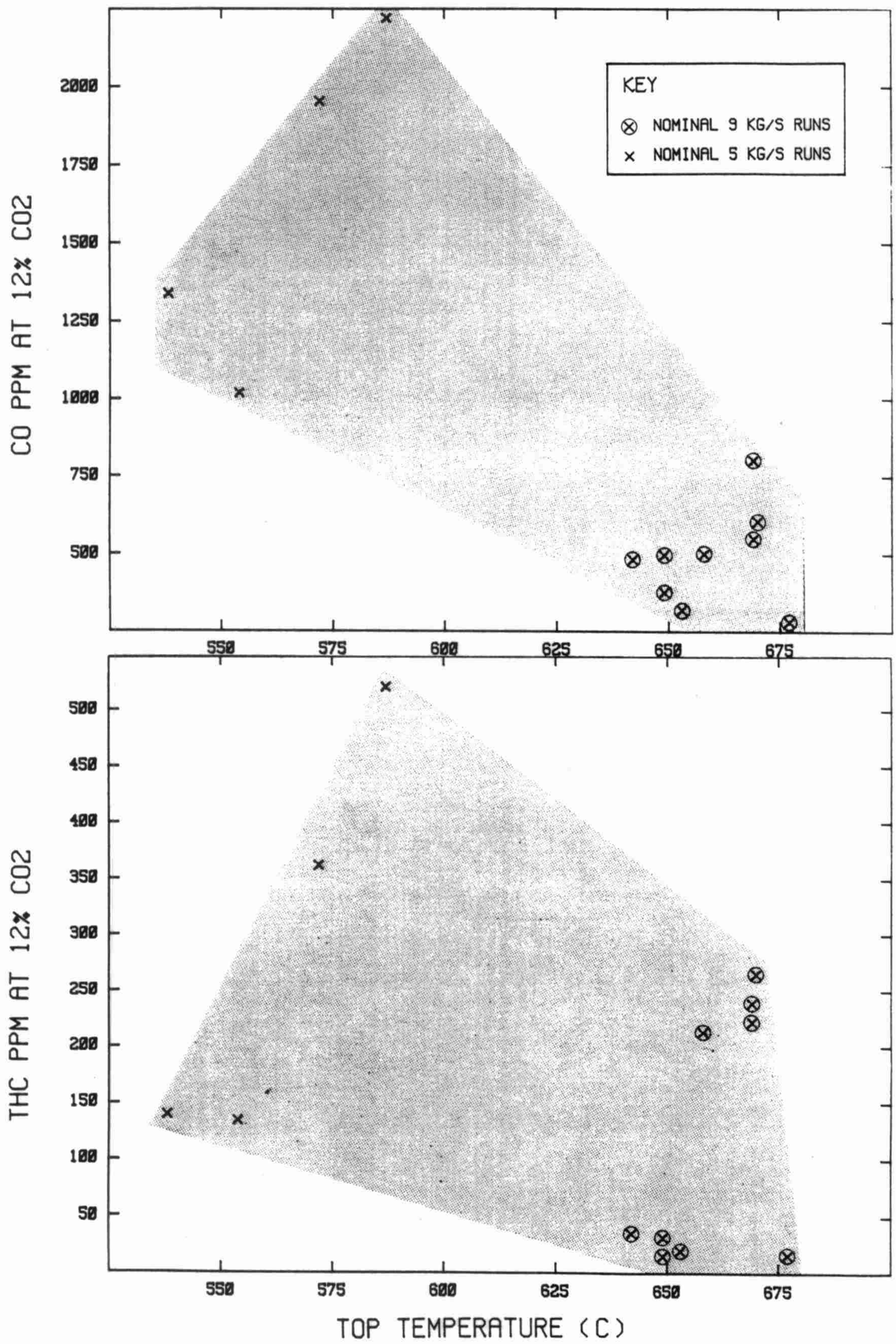


FIGURE 18 - CO AND THC CONCENTRATION vs. OF PORT VOLUME

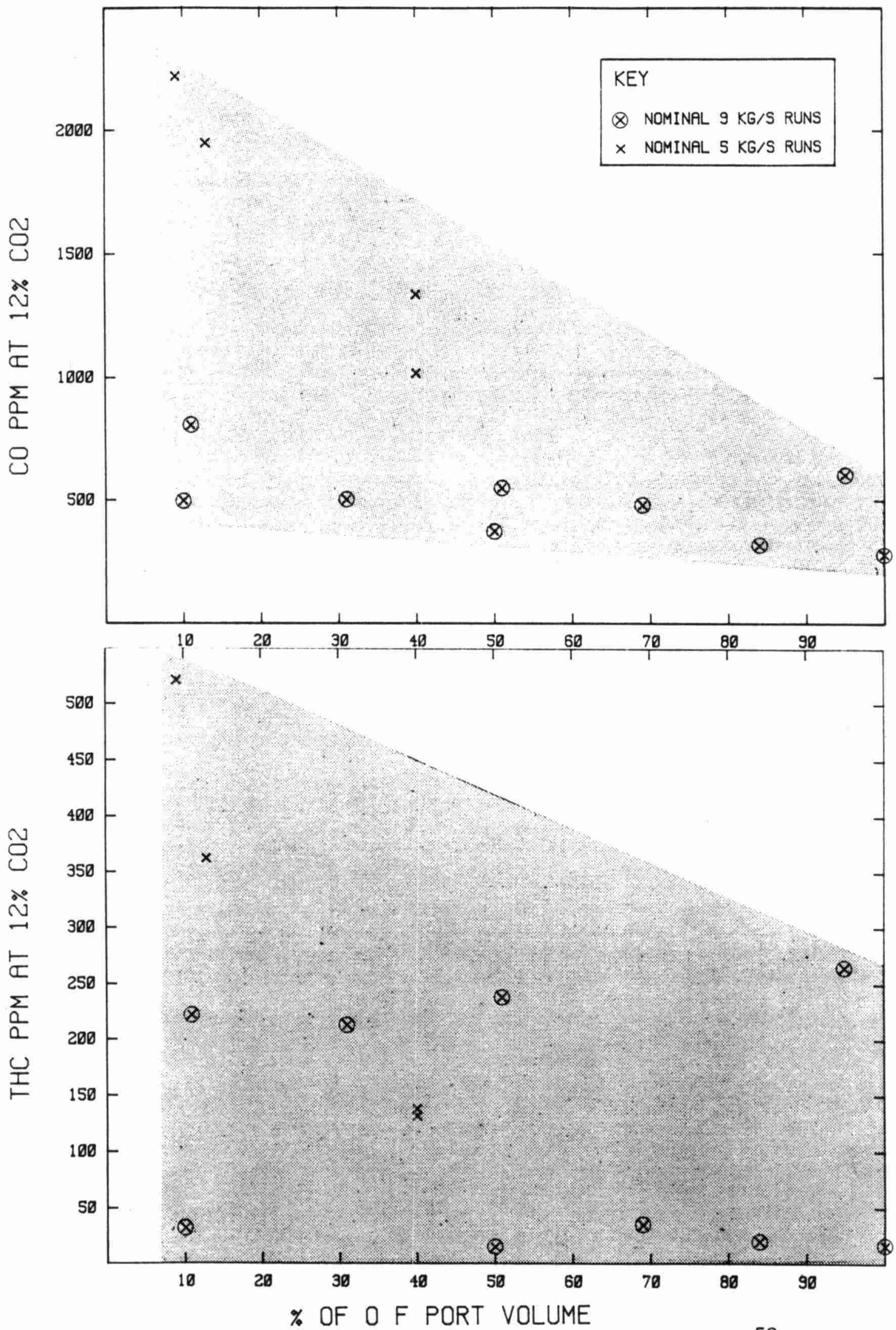


Figure 19 shows plots of average THC and CO concentration against total air for the diagnostic tests. In both cases there is the expected general trend toward higher values as total air increases, although there is considerable scatter. The data for the frequency of THC peaks and CO ppm show the same general trend, with considerable scatter.

Figure 20 shows plots of average THC and CO against fuel moisture content. These plots suggest a general trend toward higher concentrations as fuel moisture increases.

One potential disadvantage of high overfire air port use would be increased boiler carryover and it's effect on precipitator performance. Figure 21 shows plots of particulate concentration at the exit of the air heater, and the stack emission against overfire air port flow volume. These plots do not indicate either an upward or downward trend over the test range.

5.3.4 Ash

Table 8 shows the laboratory results of moisture content and higher heating value for three reduced grate and precipitator ash samples from tests 10-1 and 19-1. As indicated by the table, the calorific value of the grate ash is low, indicating good burnout. The precipitator ash has a significant and variable higher heating value.

This data and the level of combustibles in the particulate carryover after the air heater indicate incomplete burnout in the gas phase.

FIGURE 19 - CO AND THC CONCENTRATION vs. TOTAL AIR

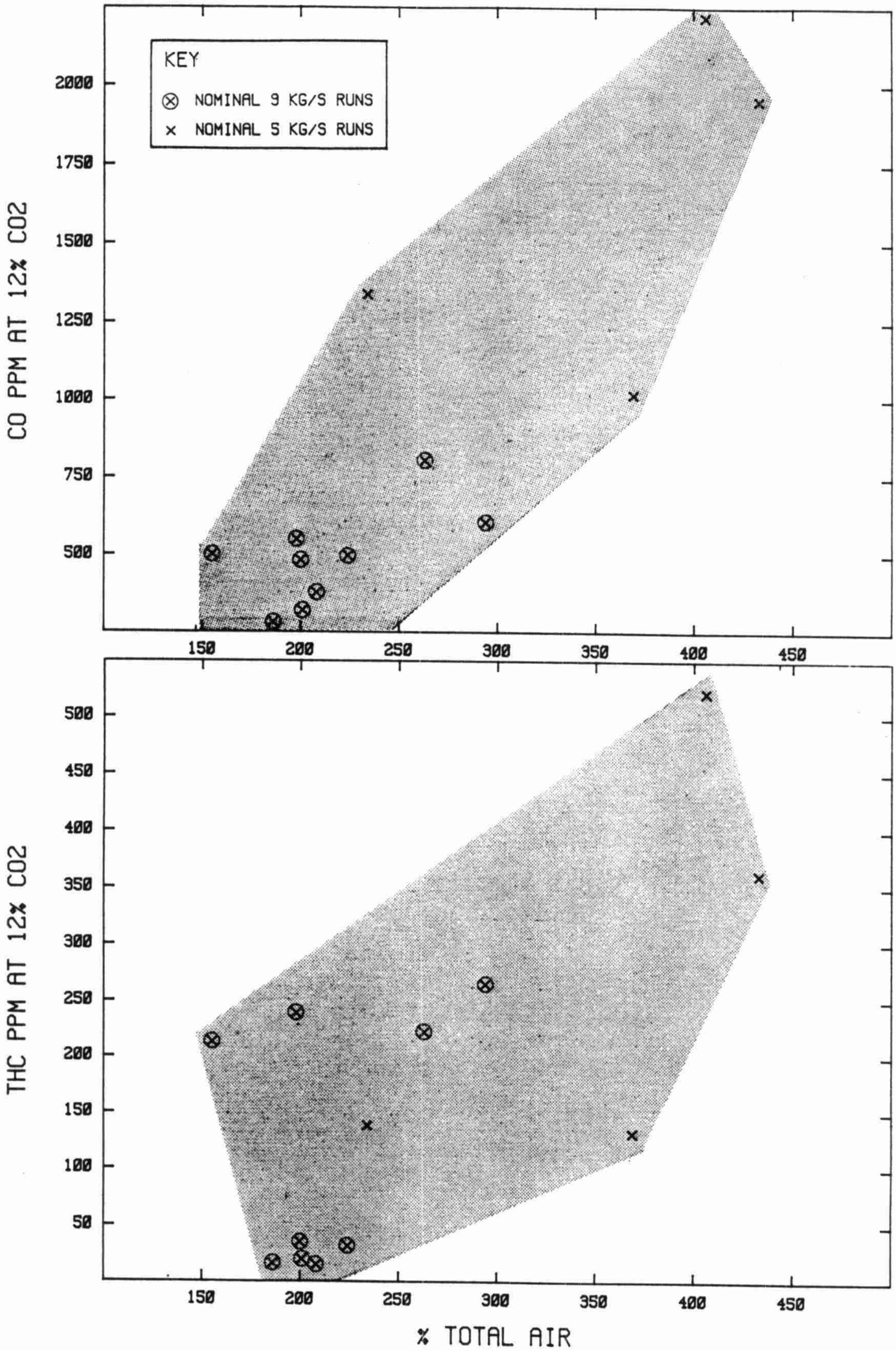


FIGURE 20 - CO AND THC CONCENTRATION vs. AIR DRY MOISTURE IN FUEL

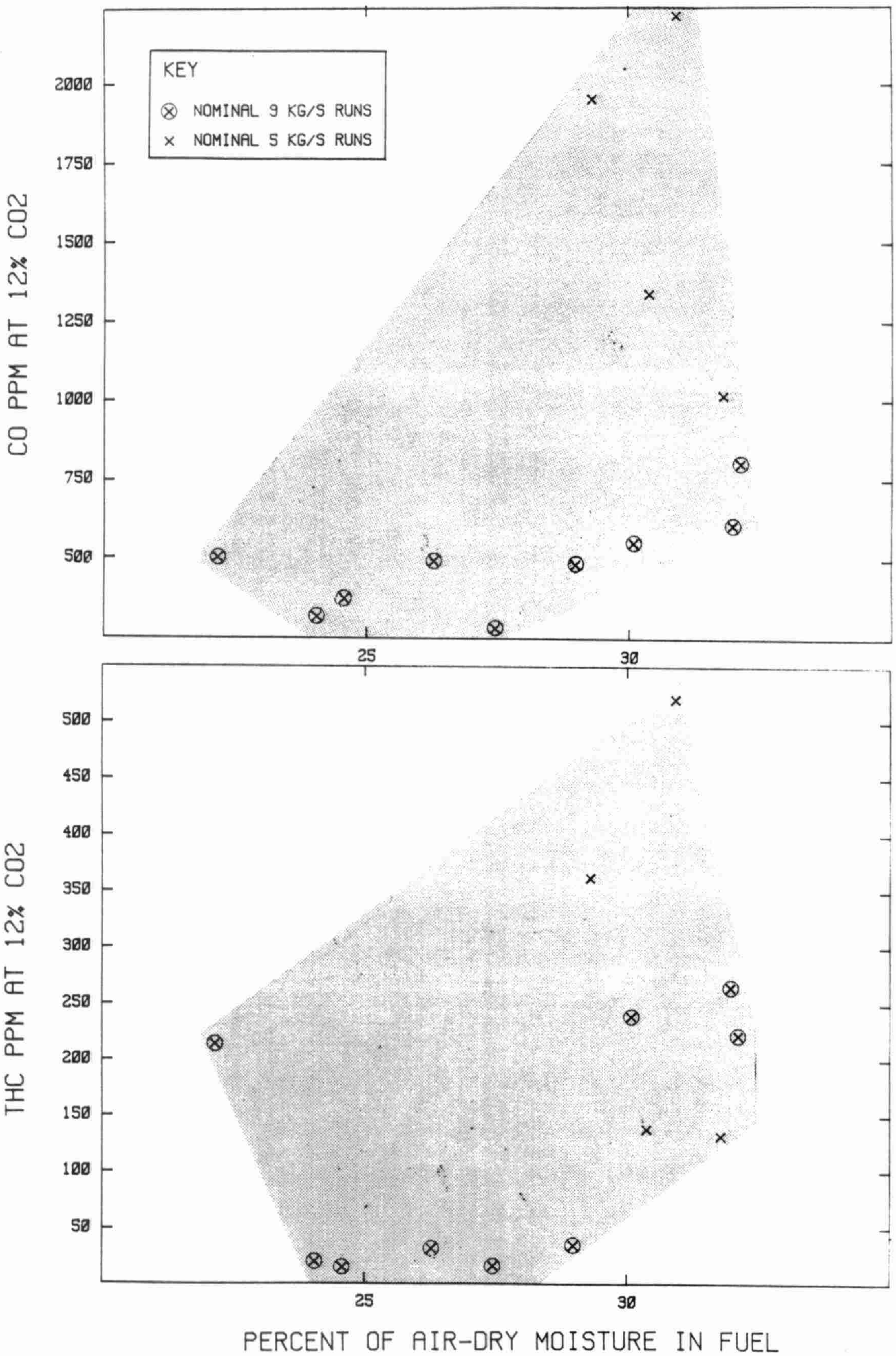


FIGURE 21 - FURNACE EXIT PARTICULATE AND STACK EMISSIONS vs. OF PORT VOLUME

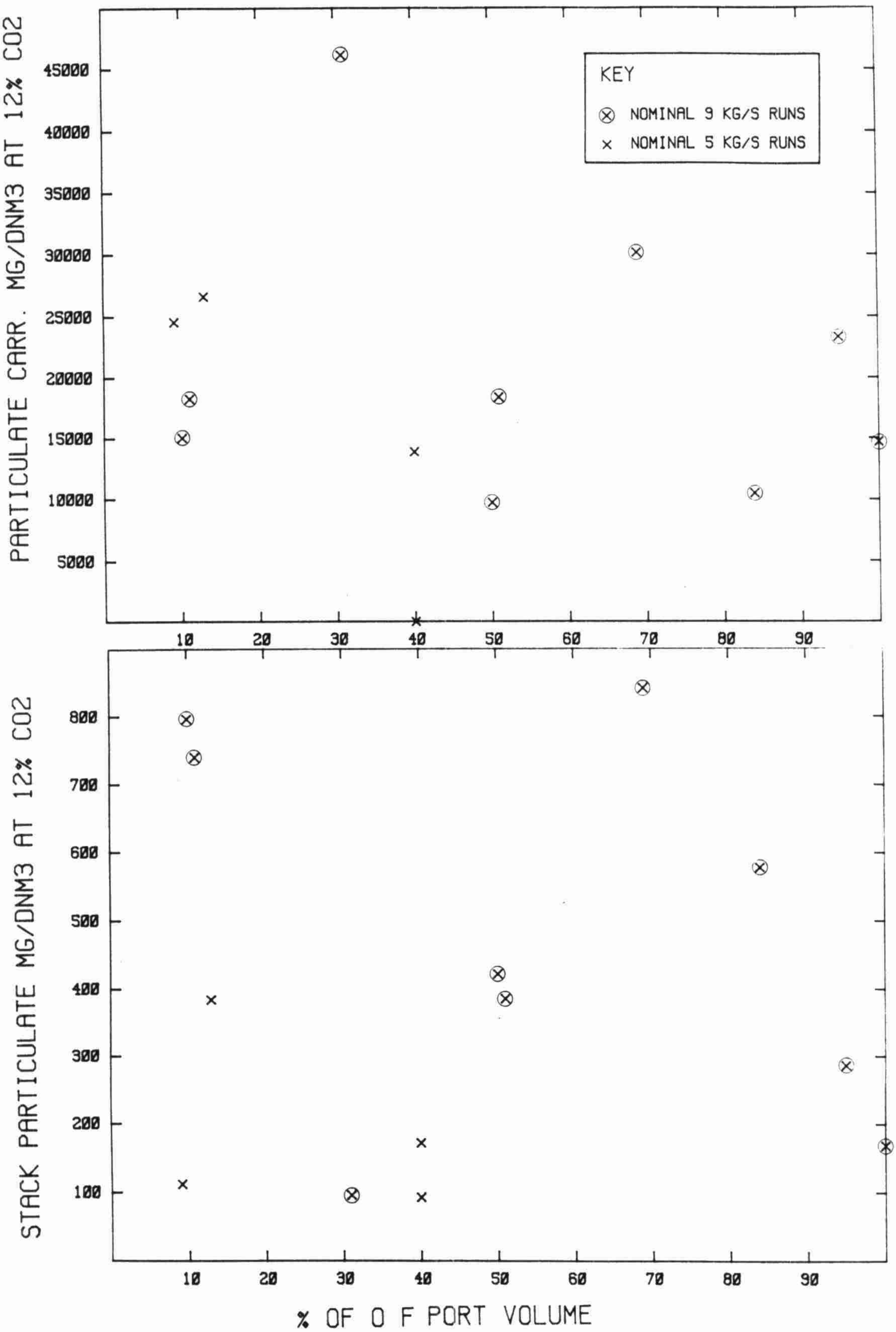


TABLE 8

ASH SAMPLE ANALYSIS

SAMPLE		PRECIPITATOR ASH			BOTTOM ASH		
		High Heating Value		Moisture	High Heating Value		Moisture
		k Joules/g	(BTU/lb)		k Joules/g	(BTU/lb)	
10-1	T-1	.07	(30)	44.4	.02	(10)	31.8
	T-2	1.32	(570)	58.2	.02	(10)	28.8
	T-3	.02	(10)	56.6	.02	(10)	27.5
Average $\pm$ Std. Dev.		.47	(203)	53.1	.02	(10)	29.4
		.74	(318)	8.0	.02	(10)	2.2
19-1	T-1	1.63	(700)	54.7	.02	(10)	23.7
	T-2	.84	(360)	51.7	.09	(10)	25.5
	T-3	1.28	(550)	56.9	.02	(10)	30.6
Average $\pm$ Std. Dev.		1.25	(537)	54.4	.04	(20)	26.6
		.40	(170)	2.6	.04	(17.3)	3.6

Tables 9 and 10 show the results of the dioxin, furan and precursor analyses of the bottom ash samples and precipitator ash samples as reported by Ontario Research Foundation. Levels for the grate ash samples are generally near the respective detectability levels but show considerable variations. Levels for the precipitator ash are significantly higher, but also show considerable variations.

Table 11 shows an overall mass balance for the dioxins, furans and precursors for the low and high load tests. These mass balances were based on:

- the average concentrations for each contaminant in the fuel, grate ash and precipitator ash (ug/g),
- the mass emission rate in the stack (ug/s) from the ORF data,

the averaged grate and precipitator ash rates measured,

and - a calculated full rate based on the ash contents from Runs 10-1 and 19-1 and the total averaged grate ash, precipitator ash and stack particulate emission rate.

In view of the very limited number of samples analyzed, these results can only be expected to show order of magnitude trends. The values shown in the table suggest that a very small proportion of the mass of these contaminants is found in the grate ash. In several cases, a significant proportion is indicated in the precipitator ash, but the predominant quantities are contained in the flue gas. The ratios of the amounts entering to the amount leaving suggest little variation for dioxins and chlorophenols, and a very substantial decrease in PCB's. The ratios also suggest substantial increases in furans and chlorobenzenes.

5.3.5 ASME Combustion and Boiler Efficiency Results

The ultimate analysis, HHV and other directly measured data for tests 10-1 and 19-1 were used to determine incineration efficiency using a heat loss method

TABLE 9

DIOXIN, FURAN AND PRECURSOR CONCENTRATIONS IN GRATE ASH SAMPLES

RUN	DIOXINS ng/g	FURANS ng/g	CHLOROBENZENES ng/g	PCB's ng/g	CHLOROPHENOLS ng/g
1	0.6	1.1	1.1	2.0	3.0
4	ND	ND	ND	0.5	ND
5	ND	ND	ND	0.3	3.0
6	NA	NA	ND	0.4	ND
7	ND	1.3	0.2	0.3	ND
8	0.7	ND	ND	0.2	1.0
9	0.4	0.4	ND	ND	3.0
10	0.1	ND	ND	ND	1.5
11	0.1	ND	ND	0.4	6.0
12	0.5	ND	0.8	0.2	5.0
13	0.1	ND	ND	0.3	10.0
14	3.3	3.9	ND	ND	2.0
15	0.4	ND	ND	0.4	4.0
Average	0.5	0.6	0.2	0.4	3.0

ND = None Detected
NA = Not Analyzed

TABLE 10

DIOXIN, FURAN AND PRECURSOR CONCENTRATIONS IN PRECIPITATOR ASH SAMPLES

RUN	DIOXINS ng/g	FURANS ng/g	CHLOROBENZENES ng/g	PCB's ng/g	CHLOROPHENOLS ng/g
1	32.5	89	20.0	4.0	ND
4	94.2	105	4.4	3.4	240
5	33.3	70	2.4	2.8	26
6	11.2	31	2.4	0.4	15
7	14.4	54	2.6	0.9	22
8	9.5	49	4.4	2.2	16
9	7.7	24	3.2	0.4	ND
10	17.3	29	1.6	0.9	52
11	9.6	36	1.0	ND	17
12	16.9	22	2.0	ND	26
13	10.8	33	1.1	1.0	30
14	35.3	41	3.0	0.4	100
15	6.2	23	6.2	1.7	20
Average	23.0	46.	4.2	1.4	43

ND = None Detected

TABLE 11

SYSTEM MASS BALANCE

STEAMING RATE (5 kg/s)		DIOXINS	FURANS	CHLOROBENZENES	PCB'S	CHLOROPHENOLS
				CONTAMINANTS		
Entering Boiler: Fuel		38.10	4.43	24.24	220.30	1,002.98
Exiting Boiler:						
Grate Ash	(ug/s)	.26	.31	.12	.22	1.57
Precip. Ash	(ug/s)	3.25	6.58	.59	.20	6.07
Flue Gas	(ug/s)	37.37	62.48	421.55	5.87	1,100.26
Total Exiting	(ug/s)	40.88	69.37	422.26	6.29	1,107.90
Ratio of Exiting/Entering		1.1	15.7	17.4	.03	1.1
STEAMING RATE (9 kg/s)						
Entering Boiler: Fuel		47.47	5.52	30.21	274.53	1,244.91
Exiting Boiler:						
Grate Ash	(ug/s)	.30	.34	.14	.24	1.77
Precip. Ash	(ug/s)	5.54	11.23	1.01	.34	10.36
Flue Gas	(ug/s)	47.93	120.35	839.76	8.52	869.94
Total Exiting	(ug/s)	53.77	131.92	840.91	9.10	882.07
Ratio of Exiting/Entering		1.1	23.9	27.8	.03	.71

developed from ASME PTC 33-1978, Large Incinerators. This data was also used to determine boiler thermal efficiency using the Abbreviated Heat Loss Method as described in ASME PTC 4.1-1974, Steam Generating Units.

Results are as follows:

For Run 10-1	Incinerator Efficiency 99.69%
	Boiler Thermal Efficiency 55.7%
For Run 19-1	Incineration Efficiency 99.15%
	Boiler Thermal Efficiency 42.6%

5.3.6 Stack Emissions

The results of the dioxin and furan analysis for each diagnostic test are shown in Appendix II. These results show a considerable range in values, with dioxin concentrations normalized to 12% CO_2 varying from 1.3 ug/Nm^3 to 11.1 ug/m^3 and nomalized furan concentrations varying from 3.7 ug/m^3 to 12.5 ug/m^3, which indicates that changes in parameters for the diagnostic tests were sufficient to affect the emission concentrations of these compounds. However, some caution must be used in the interpretation of this data, since the sampling durations were of minimal length, and protocol for sampling and analysis is in the developmental stages and is very complex. As indicated by Ontario Research Foundation the confidence limits for dioxin and furan, based on the phases of the protocol for which replicate analyses are available, are about 28% and 21% respectively. Recent research conducted on a similar protocol for dioxin sampling and analysis by Battelle Columbus Laboratories Reference: (Symposium on Land, Disposal, Incineration and Treatment of Hazardous Waste, Ft Mitchell KY, March 1983), indicates that the sample to sample variability could exceed 50%.

Although attempts were made to correlate dioxin and furan concentrations to an extensive series of parameters measured, the results were not definitive. The plotted results and a discussion of four of these efforts follows.

Figure 22 shows plots of dioxin and furan concentrations against furnace top temperature. Although there was no identified trend in the dioxin data, there appears to be a very weak trend toward increasing furan concentrations with increasing top temperature.

Figure 23 shows dioxin and furan concentrations against overfire air port flow. Once again, there was no identified trend in the dioxin data, but there appears to be a weak trend toward increasing furan concentrations at increased overfire air port flow.

Figure 24 shows plots of dioxin and furan concentrations against total air. In this case there is no apparent furan trend, but appears to be a weak trend toward higher concentrations and a broader range of concentrations of dioxins as the total air increases.

Figure 25 shows dioxin and furan concentrations against total hydrocarbon levels. In both cases there is a weak trend toward higher values as hydrocarbon concentrations increase, suggesting some support for the premise that dioxin, furan and hydrocarbon concentrations are related, although other parameters are obviously important.

Particulate concentrations at the stack against gas flow and temperature entering the precipitator are shown in Figure 26. The expected trends of greater emission variability with increased gas flowrate and temperature are evident, but other parameters are obviously important.

APPENDIX I

COMBUSTION TEST DATA TITLE DESCRIPTIONS

Run No:	Run Number; Date - Test Number
Start Time Finish Time:	Start and Finish time of test based on 24 hour clock.
Steam Flow kg/s	Steaming rate of the boiler corrected to the design pressure.
Overfire Air Distribution:	The damper positions for the front and back overfire air supply plenums.

Temperatures:

Lower & Upper Furnace ºC:
Average of five selected points on each thermocouple grid, averaged over the time of the test.

Top ºC:
Single point temperature reading from a thermocouple in the roof of the furnace, averaged over the time of the test.

Dry Flue Gas Analysis:

O_2, CO_2, CO, SO_2, THC:
Readings recorded manually at five minute intervals, and averaged over the traverse time.

Note: Estimated averages were determined by observation of the charts.

Combustion Efficiency %

$$\% = \frac{C_{co2} - C_{co}}{C_{co2}} \times 100$$

where C_{co2} = Concentration of CO_2
C_{co} = Concentration of CO

Reference: U.S. Regulation 40 CFR 761 'Polychlorinated Biphenols (PCB)' Section 40, 'Incineration'

Flue Gas Moisture: % Moisture by volume of Flue Gas

SWARU COMBUSTION STUDY
COMBUSTION RUN DATA

April 1983

RUN NO.	12-1	12-2	12-3	13-1	13-2
START TIME	17:25	18:34	20:27	19:35	20:50
FINISH TIME	18:05	19:41	21:18	20:05	22:09
STEAM FLOW kg/s	7.10 ± .56	7.13 ± .58	7.31 ± .51	6.80 ± .66	6.80 ± .71
OVERFIRE AIR DISTRIBUTION					
UPPER BACK	CLOSED	CLOSED	CLOSED	CLOSED	CLOSED
LOWER BACK	CLOSED	CLOSED	CLOSED	CLOSED	CLOSED
UPPER FRONT	CLOSED	CLOSED	CLOSED	CLOSED	CLOSED
LOWER FRONT	CLOSED	CLOSED	CLOSED	CLOSED	CLOSED
LOWER FURNACE TEMPERATURE C	667	667	589	603	N/A
UPPER FURNACE TEMPERATURE C	702	607	574	599	N/A
TOP TEMPERATURE C	N/A	N/A	N/A	567	N/A
AIR HEATER EXIT GAS TEMP C	294	355	343	N/A	N/A
DRY FLUE GAS ANALYSIS					
O_2 %	14*	14*	12.6*	15.2*	16.0*
CO_2 %	8.2*	7.0*	9.2*	6.0*	5.4*
CO PPM	942*	550*	535*	957*	462*
SO_2 PPM	N/A	N/A	N/A	N/A	N/A
HC PPM	N/A	27*	12*	231*	5*
COMBUSTION EFFICIENCY %	98.852	99.214	99.418	98.405	99.144
FLUE GAS MOISTURE (H_2O)	N/A	N/A	N/A	N/A	N/A

* Estimated Average

SWARU COMBUSTION STUDY
COMBUSTION RUN DATA

April 1983

RUN NO.	14-1	15-1	15-2	15-3	18-1
START TIME	17:00	14:59	16:10	16:56	16:38
FINISH TIME	20:10	15:25	16:30	20:37	19:40
STEAM FLOW kg/s	N/A	10.71 ± 2.20	12.98 ± .56	N/A	N/A
OVERFIRE AIR DISTRIBUTION					
UPPER BACK	N/A	CLOSED	CLOSED	N/A	N/A
LOWER BACK	N/A	CLOSED	WO	N/A	N/A
UPPER FRONT	N/A	CLOSED	CLOSED	N/A	N/A
LOWER FRONT	N/A	CLOSED	CLOSED	N/A	N/A
LOWER FURNACE TEMPERATURE C	N/A	954	872	N/A	N/A
UPPER FURNACE TEMPERATURE C	N/A	852	798	N/A	N/A
TOP TEMPERATURE C	N/A	706	703	N/A	N/A
AIR HEATER EXIT GAS TEMP C	N/A	358	N/A	N/A	N/A
DRY FLUE GAS ANALYSIS					
O_2 %	14.8*	10.5 ± 3	8.9 ± 1.9	14.5*	14.5*
CO_2 %	5.9*	9.1 ± 3	11.4 ± 1.7	6.6*	6.0*
CO PPM	659*	126 ± 943	1179 ± 484	553*	457*
SO_2 PPM	N/A	N/A	N/A	N/A	N/A
HC PPM	70*	N/A	N/A	N/A	N/A
COMBUSTION EFFICIENCY %	98.883	98.605	98.966	99.162	99.238
FLUE GAS MOISTURE (H_2O)	N/A	10.4	N/A	N/A	N/A

* Estimated Average

SWARU COMBUSTION STUDY
COMBUSTION RUN DATA

April 1983

RUN NO.	19-1	19-2	19-3	19-4	19-5
START TIME	14:30	15:45	17:10	19:00	20:35
FINISH TIME	15:06	16:20	18:00	19:45	21:20
STEAM FLOW kg/s	5.59 ± 1.26	5.37 ± 2.20	5.46 ± 1.01	5.15 ± 2.40	5.43 ± .73
OVERFIRE AIR DISTRIBUTION					
UPPER BACK	CLOSED	CLOSED	CLOSED	CLOSED	CLOSED
LOWER BACK	CLOSED	WO	WO	WO	CLOSED
UPPER FRONT	CLOSED	CLOSED	CLOSED	CLOSED	CLOSED
LOWER FRONT	CLOSED	CLOSED	CLOSED	HALF OPEN	CLOSED
LOWER FURNACE TEMPERATURE C	761	765	772	667	689
UPPER FURNACE TEMPERATURE C	562	589	585	544	607
TOP TEMPERATURE C	576	564	632	N/A	563
AIR HEATER EXIT GAS TEMP C	N/A	307	283	N/A	317
DRY FLUE GAS ANALYSIS					
O_2 %	14.3 ± 1.3	14.6 ± 1.7	15.2 ± 1.1	15.5 ± 1.5	15.8 ± 1.4
CO_2 %	6.7 ± 1.1	6.2 ± 1.4	5.7 ± 1.1	5.8 ± 1.4	4.9 ± 1.3
CO PPM	452 ± 222	900 ± 373	524 ± 333	319 ± 163	735 ± 466
SO_2 PPM	66 ± 19	58 ± 12	61 ± 13	40.1 ± 9	52 ± 39
HC PPM	N/A	N/A	N/A	N/A	N/A
COMBUSTION EFFICIENCY %	99.325	98.548	99.081	99.450	98.500
FLUE GAS MOISTURE (H_2O)	N/A	11.8	3.5	19.5	N/A

SWARU COMBUSTION STUDY
COMBUSTION RUN DATA

April 1983

RUN NO.	20-1	20-2	20-3	20-4
START TIME	14:00	15:05	17:20	20:30
FINISH TIME	14:26	15:40	18:09	21:30
STEAM FLOW kg/s	8.46 ± .76	7.96 ± .54	9.04 ± .972	7.90 ± .10
OVERFIRE AIR DISTRIBUTION				
UPPER BACK	CLOSED	CLOSED	CLOSED	CLOSED
LOWER BACK	CLOSED	WO	WO	WO
UPPER FRONT	CLOSED	CLOSED	CLOSED	WO
LOWER FRONT	CLOSED	CLOSED	CLOSED	WO
LOWER FURNACE TEMPERATURE C	782	558	760	756
UPPER FURNACE TEMPERATURE C	678	543	686	637
TOP TEMPERATURE C	702	566	717	687
AIR HEATER EXIT GAS TEMP C	353	317	356	339
DRY FLUE GAS ANALYSIS				
O_2 %	7.1 ± 1.2	8.8 ± 1.6	8.4 ± 2.5	9.9 ± 2.1
CO_2 %	12.9 ± 2.4	12.1 ± 1.6	11.7 ± 2.1	10.5 ± 1.8
CO PPM	491 ± 188	427 ± 246	906 ± 482	687 ± 309
SO_2 PPM	N/A	N/A	N/A	N/A
HC PPM	22 ± 16	141 ± 347	209 ± 317	92 ± 140
COMBUSTION EFFICIENCY %	99.619	99.647	99.226	99.346
FLUE GAS MOISTURE (H_2O)	N/A	N/A	14	17

SWARU COMBUSTION STUDY
COMBUSTION RUN DATA

April 1983

RUN NO.	25-1	25-2	25-3	25-4	25-5
START TIME	15:45	18:10	22:05	23:25	23:40
FINISH TIME	15:55	20:51	23:04	23:40	24:03
STEAM FLOW kg/s	6.29	5.12 ± .59	N/A	5.04 ± 1.43	4.41 ± .89
OVERFIRE AIR DISTRIBUTION					
UPPER BACK	CLOSED	CLOSED	CLOSED	CLOSED	CLOSED
LOWER BACK	WO	WO	WO	WO	WO
UPPER FRONT	CLOSED	CLOSED	CLOSED	CLOSED	CLOSED
LOWER FRONT	CLOSED	CLOSED	CLOSED	CLOSED	CLOSED
LOWER FURNACE TEMPERATURE C	N/A	556	503	588	506
UPPER FURNACE TEMPERATURE C	N/A	552	494	536	486
TOP TEMPERATURE C	N/A	571	514	589	508
AIR HEATER EXIT GAS TEMP C	N/A	287	291	310	293
DRY FLUE GAS ANALYSIS					
O_2 %	11.8 ± 2.4	10.4 ± 2.1	13.0 ± 3.5	11.4 ± 3.9	11.0 ± 3.7
CO_2 %	8.5 ± 2.6	9.8 ± 2.1	7.7 ± 3.4	9.0 ± 3.5	10.1 ± 4.1
CO PPM	773 ± 326	783 ± 450	937 ± 580	469 ± 356	868 ± 373
SO_2 PPM	N/A	N/A	N/A	N/A	N/A
HC PPM	26 ± N/A	60 ± 63	280 ± 178	187 ± 121	222 ± 94
COMBUSTION EFFICIENCY %	99.091	99.201	98.783	99.479	99.141
FLUE GAS MOISTURE (H_2O)	N/A	10	11	N/A	N/A

SWARU COMBUSTION STUDY
COMBUSTION RUN DATA

April 1983

RUN NO.	26-1	26-2	27-1	27-2
START TIME	18:00	21:40	14:30	17:20
FINISH TIME	20:00	23:30	16:30	18:52
STEAM FLOW kg/s	5.12 ± .72	9.42 ± .32	9.03 ± 5.80	8.97 ± .340
OVERFIRE AIR DISTRIBUTION				
UPPER BACK	CLOSED	CLOSED	CLOSED	CLOSED
LOWER BACK	WO	WO	WO	WO
UPPER FRONT	CLOSED	CLOSED	CLOSED	CLOSED
LOWER FRONT	CLOSED	CLOSED	CLOSED	CLOSED
LOWER FURNACE TEMPERATURE C	528	699	753	834
UPPER FURNACE TEMPERATURE C	523	678	813	664
TOP TEMPERATURE C	543	674	648	676
AIR HEATER EXIT GAS TEMP C	302	360	340	350
DRY FLUE GAS ANALYSIS				
O_2 %	11.6 ± 2.0	8.3 ± 3.2	8.5 ± 1.9	7.2 ± 1.4
CO_2 %	8.9 ± 1.9	11.8 ± 2.94	12.2 ± 1.7	13.2 ± 1.2
CO PPM	853 ± 488	794 ± 1123	1174 ± 1918	1101 ± 778
SO_2 PPM	N/A	N/A	N/A	137 ± 19
HC PPM	80 ± 55	182 ± 276	262 ± 409	321 ± 592
COMBUSTION EFFICIENCY %	99.038	99.327	99.034	99.165
FLUE GAS MOISTURE (H_2O)	9	6	10	5

SWARU COMBUSTION STUDY
COMBUSTION RUN DATA

April 1983

RUN NO.	28-1	28-2
START TIME	10:40	19:34
FINISH TIME	11:40	20:48
STEAM FLOW kg/s	5.11 $\pm$ .14	N/A
OVERFIRE AIR DISTRIBUTION		
UPPER BACK	CLOSED	N/A
LOWER BACK	WO	N/A
UPPER FRONT	CLOSED	N/A
LOWER FRONT	CLOSED	N/A
LOWER FURNACE TEMPERATURE C	573	547
UPPER FURNACE TEMPERATURE C	514	514
TOP TEMPERATURE C	550	569
AIR HEATER EXIT GAS TEMP. C	303	310
DRY FLUE GAS ANALYSIS		
O_2 %	12.1 $\pm$ 3.1	N/A
CO_2 %	9.1 $\pm$ 3.2	N/A
CO PPM	889 $\pm$ 614	N/A
SO_2 PPM	55 $\pm$ 20	N/A
HC PPM	166 $\pm$ 137	N/A
COMBUSTION EFFICIENCY %	99.026	
FLUE GAS MOISTURE (H_2O)	N/A	N/A

SWARU COMBUSTION STUDY
COMBUSTION RUN DATA

April 1983

RUN NO.	29-1	29-2	29-3	29-4
START TIME	11:05	18:45	20:05	21:20
FINISH TIME	11:35	19:32	21:00	21:33
STEAM FLOW kg/s	8.38 ± .81	7.52 ± 1.03	8.48 ± .80	7.43 ± .18
OVERFIRE AIR DISTRIBUTION				
UPPER BACK	CLOSED	WO	WO	WO
LOWER BACK	WO	WO	WO	WO
UPPER FRONT	CLOSED	WO	CLOSED	WO
LOWER FRONT	CLOSED	WO	WO	WO
LOWER FURNACE TEMPERATURE C	691	657	702	551
UPPER FURNACE TEMPERATURE C	625	607	614	519
TOP TEMPERATURE C	611	667	633	545
AIR HEATER EXIT GAS TEMP C	353	348	351	320
DRY FLUE GAS ANALYSIS				
O_2 %	10.0 ± 1.8	11.7 ± 3.1	10.8 ± 1.5	12.9 ± 2.9
CO_2 %	10.7 ± 1.7	8.7 ± 2.9	9.4 ± 1.4	7.4 ± 3.0
CO PPM	338 ± 197	878 ± 625	503 ± 276	947 ± 670
SO_2 PPM	32 ± 8	35 ± 13	29 ± 6	31 ± 13
HC PPM	26 ± 40	104 ± 129	17 ± 28	40 ± 57
COMBUSTION EFFICIENCY %	99.683	98.987	99.464	98.720
FLUE GAS MOISTURE (H_2O)	10	N/A	N/A	N/A

APPENDIX II

Diagnostic Test Data Part I: Title Descriptions

Steam Flow kg/s:	Steaming rate of furnace corrected to design pressure.
Overfire Air Distribution:	The damper positions for the front and back overfire air supply plenums.

<u>Size Distribution by Weight of Air Dry Fuel:</u>

Oversize:	% by weight of dry fuel which by inspection, has a major dimension of 100 mm or larger.
58.8 mm %:	% by weight of dry fuel which passed a 58.8 mm mesh, but does not include oversize
58.8 12.7 mm %:	% by weight of dry fuel which passed a 58.8 mm mesh but did not pass a 12.7 mm mesh
12.7 mm %:	% by weight of dry fuel which passed a 12.7 mm mesh.
Fuel Air Dry Moisture %:	The % by weight of the moisture in the fuel which was removed when dried in ambient air conditions.
Total Air %:	$100 \times \frac{(1 + (O_2 - CO/2))}{.264\, N_2 - (O_2 - CO/2)}$ Reference: Babcock and Wilcox 1972, Steam: It's Generation and Use's 38th Edition, New York, N.Y.
Bottom Ash g/s:	Dry ash flow rate off the grate.
Particulate Carryover g/s	Particulate mass flowrate at the inlet to the electrostatic precipitator.
Combustibles %:	% combustibles by weight of particulate carryover
Precipitator Ash %:	Dry ash flowrate leaving the precipitator
Stack Concentration mg/Nm^3:	ORF results corrected to 12% CO_2

Diagnostic Test Data Part 2: Title Descriptions

Run No.: Run Number - date- test/traverse number

Start Time: Finish Time: Start and Finish time of test Based on 24 hr clock.

Grate Conditions: Observations made through the furnace viewing ports. Basic criterion was the development of piles of burning fuel on the grate.

Steam Flow: Steaming Rate of the Boiler corrected to design pressure.

Air Flow (% of Comb. Air Supplied):

% based on rates obtained using the Helium tracer method, corrected to standard conditions.

Combustion air suplied is the sum of undergrate and overfire air volumes.

Undergrate: $\frac{\text{FD Fan Air Rate}}{\text{Comb. Air Supplied}} \times 100$

Overfire: $\frac{\text{OF Fan Air Rate}}{\text{Comb Air. Supplied}} \times 100$

Chute Infiltration: $\frac{\text{Chute Infiltration Air Rate}}{\text{Comb. Air Supplied}} \times 100$

Air Heater Exit Gas: $\frac{\text{Rate of Gases at Air Heater Exit}}{\text{Comb. Air Supplied}} \times 100$

Temperatures:

Grate: Averaged of the six undergrate thermocouples, averaged over the traverse time, $\pm$ standard deviation of the values.

Lower & Upper Furnace: Average of five selected points on each thermocouple grid, averaged over the traverse time, $\pm$ standard deviation.

Top: Single point temperature reading from a thermocouple in the roof of the furnace, averaged over the traverse time $\pm$ standard deviation.

Dry Flue Gas Analysis: O_2, CO_2, CO, SO_2, THC

Average reading, recorded manually at five minute intervals, $\pm$ standard deviation.

Combustion Efficiency:

$$\frac{C_{co_2} - C_{co}}{C_{co_2}} \times 100$$

where: C_{co_2} = concentration of CO_2
C_{co} = concentration of CO

Reference: U.S. Regulation, 40 CFR 761 'Polychlorinated Biphenols (PCB)', section 40, 'Incineration'.

Peaks/hr: The number of peaks per hour above the value quoted, for THC and CO, determined from the charts.

Flue Gas Volume: (m^3/h): Determined from pitot traverse data after the exit from the air heater. Wet basis and at stack temperatures.

Nm^3/hr: Dry basis with a reference temperature of 0^oC.

Flue Gas: Moisture: % moisture by volume of Flue Gas

Opacity %: Average of readings from plant Opacity meter $\pm$ standard deviation.

Opacity Peak/hr 20%: The number of peaks per hour above 20% opacity.

SWARU COMBUSTION STUDY
DIAGNOSTIC TEST DATA PART 1

April 21, 1983
Run: 21-1

Steam Flow		kg/s	8.51
Overfire Air Distribution			
	Upper Back		Closed
	Lower Back		Open
	Upper Front		Closed
	Lower Front		Closed
Size Distribution by Weight of Air Dry Fuel			
	Oversize	%	16.17
	>50.8 mm.	%	19.59
<50.8	>12.7 mm.	%	35.98
	<12.7 mm.	%	28.27
Fuel Air Dry Moisture		%	22.16 ± 10.47
Total Air		%	155
Bottom Ash		g/s	N/A
Particulate Carryover		g/s	466
Combustibles		%	9.8
Precipitator Ash		g/s	N/A
Stack Concentration			
	Particulate	mg/Nm^3*	95
	Dioxin	ug/Nm^3*	2.2
	Furan	ug/Nm^3*	7.7
	Chlorobenzenes	ug/Nm^3*	47.9
	PCBs	ug/Nm^3*	161.1
	Chlorophenols	ug/Nm^3*	37.0

* Trace organic concentrations corrected to 12% CO_2

SWARU COMBUSTION STUDY
DIAGNOSTIC TEST DATA PART 2

April 21, 1983

RUN NO.	21-1/T1	21-1/T2	21-1/T3	21-1/AVE
START TIME	11:30	14:30	17:31	11:30
FINISH TIME	13:00	15:55	18:44	18:44
GRATE CONDITIONS	Some Piling	Little Piling	Little Piling	
STEAM FLOW kg/s	8.83 ± .69	8.70 ± .89	7.99 ± .98	8.51 ± .89
AIR FLOW (% of Comb. Air Supplied)				
UNDERGRATE	N/A	N/A	N/A	N/A
OVERFIRE	N/A	N/A	N/A	N/A
CHUTE INFILTRATION	N/A	N/A	N/A	N/A
AIR HEATER EXIT GAS	N/A	N/A	N/A	N/A
GRATE TEMPERATURE C	242	235	243	240
LOWER FURNACE TEMPERATURE C	755	701	683	713
UPPER FURNACE TEMPERATURE C	671	648	638	652
TOP TEMPERATURE C	672	657	622	650
AIR HEATER EXIT GAS TEMP C	343	344	338	342
DRY FLUE GAS ANALYSIS				
O_2 %	6.6 ± 1.0	8.1 ± 1.4	7.7 ± 1.7	7.4 ± 1.5
CO_2 %	13.2 ± .8	11.7 ± 1.3	12.2 ± 1.8	12.4 ± 1.5
CO PPM	522 ± 314	356 ± 208	694 ± 934	518 ± 545
SO_2 PPM	N/A	N/A	N/A	N/A
THC PPM	379 ± 471	101 ± 288	165 ± 326	220 ± 387
Combustion Efficiency %	99.605	99.695	99.431	99.582
THC Peaks/h > 600 PPM	10.67	4.24	4.93	6.77
THC Peaks/h > 300 PPM	15.33	7.76	8.22	10.65
CO Peaks/h > 1500 PPM	9.33	4.94	7.40	7.26
FLUE GAS VOLUME m^3/h	N/A	N/A	N/A	98,500
FLUE GAS VOLUME Nm^3/h	N/A	N/A	N/A	35,200
FLUE GAS MOISTURE (H_2O) %	N/A	N/A	N/A	17.58
OPACITY %	12.2 ± 1.8	13.9 ± 2.0	12.8 ± .8	13.0 ± 1.8
OPACITY PEAKS/h > 20 %	4.67	3.53	4.93	4.36

SWARU COMBUSTION STUDY May 4, 1983
DIAGNOSTIC TEST DATA PART 1 Run: 4-1

Steam Flow	kg/s	4.86
Overfire Air Distribution		
Upper Back		Closed
Lower Back		Open
Upper Front		Closed
Lower Front		Closed
Size Distribution by Weight of Air Dry Fuel		
Oversize	%	3.01
>50.8 mm	%	12.54
<50.8 >12.7 mm	%	42.16
<12.7 mm	%	42.29
Fuel Air Dry Moisture	%	30.37 $\pm$ 3.37
Total Air	%	234
Bottom Ash	g/s	368
Particulate Carryover	g/s	N/A
Combustibles	%	8.9
Precipitator Ash	g/s	365
Stack Concentration		
Particulate	mg/Nm^3*	92
Dioxin	ug/Nm^3*	2.6
Furan	ug/Nm^3*	3.7
Chlorobenzenes	ug/Nm^3*	30.0
PCB's	ug/Nm^3*	122.9
Chlorophenols	ug/Nm^3*	28.4

* Trace organic concentrations corrected to 12% CO_2

SWARU COMBUSTION STUDY
DIAGNOSTIC TEST DATA PART 2

May 4, 1983

RUN NO.	4-1/T1	4-1/T2	4-1/T3	4-1/AVE
START TIME	10:08	13:30	15:55	10:02
FINISH TIME	11:25	14:55	17:15	17:15
GRATE CONDITIONS	NO PILING	NO PILING	NO PILING	
STEAM FLOW kg/s	4.83 ± .83	5.10 ± 1.22	4.66 ± .74	4.86 ± .93
AIR FLOW (% of Comb Air Supplied)				
UNDERGRATE	64	66	63	64
OVERFIRE AIR	36	34	37	36
CHUTE INFILTRATION AIR	37	36	37	37
AIR HEATER EXIT GAS	144	162	160	155
GRATE TEMPERATURE C	234 ± 14	237 ± 14	240 ± 13	237 ± 14
LOWER FURNACE TEMPERATURE C	588 ± 117	607 ± 131	598 ± 104	597 ± 117
UPPER FURNACE TEMPERATURE C	500 ± 78	514 ± 84	510 ± 79	508 ± 81
TOP TEMPERATURE C	532 ± 44	545 ± 60	538 ± 54	538 ± 52
AIR HEATER EXIT GAS TEMP C	310 ± 17	314 ± 18	312 ± 16	312 ± 17
DRY FLUE GAS ANALYSIS				
O_2 %	12.3 ± 1.9	11.5 ± 2.04	12.0 ± 2.5	11.9 ± 2.1
CO_2 %	8.6 ± 1.7	9.3 ± 2.0	8.9 ± 2.4	8.9 ± 2.0
CO PPM	1236 ± 712	1039 ± 451	700 ± 446	992 ± 575
SO_2 PPM	44 ± 10	59 ± 50	49 ± 17	51 ± 32
THC PPM	121 ± 131	79 ± 82	108 ± 121	102 ± 112
Combustion Efficiency %	98.569	98.883	99.209	98.890
THC Peaks/h > 600 PPM	0.78	0.71	0	.50
THC Peaks/h > 300 PPM	2.34	4.24	1.5	2.73
CO Peaks/h > 1500 PPM	5.45	9.88	5.25	6.94
FLUE GAS VOLUME m^3/h	N/A	N/A	N/A	N/A
FLUE GAS VOLUME Nm^3/h	N/A	N/A	N/A	N/A
FLUE GAS MOISTURE (H_2O) %	24.2	7.1	13.3	14.9
OPACITY %	6.28 ± .8	7.06 ± .8	7.28 ± .5	6.87 ± .8
OPACITY PEAKS/h > 20 %	0	0	0	0

SWARU COMBUSTION STUDY
DIAGNOSTIC TEST DATA PART 1

May 5, 1983
Run: 5-1

Steam Flow	kg/s	8.03
Overfire Air Distribution		
Upper Back		Open
Lower Back		Open
Upper Front		Closed
Lower Front		Closed
Size Distribution by Weight of Air Dry Fuel		
Oversize	%	2.66
>50.8 mm	%	10.35
<50.8 >12.7 mm	%	47.05
<12.7 mm	%	39.94
Fuel Air Dry Moisture	%	28.97 ± 7.64
Total Air	%	200
Bottom Ash	g/s	381
Particulate Carryover	g/s	189
Combustibles	%	7.8
Precipitator Ash	g/s	211
Stack Concentration		
Particulate	mg/Nm^3*	841
Dioxin	ug/Nm^3*	3.5
Furan	ug/Nm^3*	11.0
Chlorobenzenes	ug/Nm^3*	8.2
PCB's	ug/Nm^3*	345.9
Chlorophenols	ug/Nm^3*	76.8

* Trace organic concentrations corrected to 12% CO_2.

SWARU COMBUSTION STUDY
DIAGNOSTIC TEST DATA PART 2

May 5, 1983

RUN NO.	5-1/T1	5-1/T2	5-1/T3	5-1/AVE
START TIME	12:30	14:40	18:00	12:30
FINISH TIME	14:00	16:10	19:25	19:25
GRATE CONDITIONS	Moderate Piling	Moderate Piling	Heavy Piling	
STEAM FLOW kg/s	8.05 ± .46	7.80 ± .78	8.24 ± .80	8.03 ± .69
AIR FLOW (% of Comb Air Supplied)				
UNDERGRATE	71	72	71	71
OVERFIRE	29	28	29	29
CHUTE INFILTRATION AIR	24	23	23	23
AIR HEATER EXIT GAS	129	130	130	130
GRATE TEMPERATURE C	239 ± 9	244 ± 9	249 ± 11	244 ± 11
LOWER FURNACE TEMPERATURE C	731 ± 81	704 ± 76	720 ± 77	718 ± 78
UPPER FURNACE TEMPERATURE C	596 ± 145	606 ± 107	596 ± 116	599 ± 123
TOP TEMPERATURE C	645 ± 32	634 ± 36	645 ± 47	642 ± 39
AIR HEATER EXIT GAS TEMP C	365 ± 18	361 ± 19	359 ± 25	362 ± 21
DRY FLUE GAS ANALYSIS				
O_2 %	9.9 ± 1.1	10.2 ± 1.2	10.9 ± 2.1	10.3 ± 1.6
CO_2 %	10.4 ± 1.0	10.3 ± 1.0	10.0 ± 1.6	10.3 ± 1.2
CO PPM	494 ± 181	369 ± 218	362 ± 285	414 ± 236
SO_2 PPM	40 ± 8	45 ± 8	42 ± 9	43 ± 8
THC PPM	45 ± 135	17 ± 16	29 ± 22	30 ± 80
Combustion Efficiency %	99.526	99.642	99.639	99.596
THC Peaks/h 600 PPM	0.67	0	0.71	0.45
THC Peaks/h 300 PPM	1.33	1.33	1.41	1.36
CO Peaks/h 1500 PPM	1.33	2.00	1.41	1.58
FLUE GAS VOLUME m^3/h	135,000	140,000	128,000	134,000
FLUE GAS VOLUME Nm^3/h	49,000	52,000	49,100	50,000
FLUE GAS MOISTURE (H_2O) %	16.0	15.5	13.3	14.9
OPACITY %	9.2 ± 1.4	8.2 ± .8	8.8 ± 1.6	8.7 ± 1.3
OPACITY PEAKS/h 20 %	0	0	0	0

SWARU COMBUSTION STUDY
DIAGNOSTIC TEST DATA PART 1

May 6, 1983
Run: 6-1

Steam Flow	kg/s	9.21
Overfire Air Distribution		
Upper Back		Open
Lower Back		Open
Upper Front		Closed
Lower Front		Open
Size Distribution by Weight of Air Dry Fuel		
Oversize	%	7.99
>50.8 mm	%	10.79
<50.8 >12.7 mm	%	43.30
<12.7 mm	%	37.92
Fuel Air Dry Moisture	%	27.44 ± 6.07
Total Air	%	186
Bottom Ash	g/s	N/A
Particulate Carryover	g/s	199
Combustibles	%	8.8
Precipitator Ash	g/s	N/A
Stack Concentration		
Particulate	mg/Nm^3*	169
Dioxin	ug/Nm^3*	4.7
Furan	ug/Nm^3*	10.3
Chlorobenzenes	ug/Nm^3*	31.5
PCB's	ug/Nm^3*	91.4
Chlorophenols	ug/Nm^3*	37.6

* Trace organic concentrations corrected to 12% CO_2.

SWARU COMBUSTION STUDY
DIAGNOSTIC TEST DATA PART 2

May 6, 1983

RUN NO.	6-1/T1	6-1/T2	6-1/T3	6-1/AVE
START TIME	11:30	14:55	17:00	11:30
FINISH TIME	12:55	16:20	18:25	18:25
GRATE CONDITIONS	MODERATE PILING	MODERATE PILING	CONTINUOUS PILING	
STEAM FLOW kg/s	9.44 ± .71	9.24 ± .97	8.94 ± .84	9.21 ± .83
AIR FLOW (% of Comb Air Supplied)				
UNDERGRATE	69	68	68	69
OVERFIRE AIR	31	31	32	32
CHUTE INFILTRATION AIR	26	27	28	27
AIR HEATER EXIT GAS	138	140	141	140
GRATE TEMPERATURE C	249 ± N/A	257 ± N/A	257 ± N/A	254 ± N/A
LOWER FURNACE TEMPERATURE C	788 ± N/A	782 ± N/A	766 ± N/A	779 ± N/A
UPPER FURNACE TEMPERATURE C	647 ± N/A	679 ± N/A	666 ± N/A	664 ± N/A
TOP TEMPERATURE C	688 ± N/A	688 ± N/A	656 ± N/A	677 ± N/A
AIR HEATER EXIT GAS TEMP C	378 ± N/A	389 ± N/A	387 ± N/A	385 ± N/A
DRY FLUE GAS ANALYSIS				
O_2 %	9.4 ± 1.1	9.4 ± 1.5	9.5 ± 1.1	9.4 ± 1.2
CO_2	10.7 ± 1.1	10.8 ± 1.2	10.7 ± 1.2	10.7 ± 1.1
CO PPM	329 ± 151	223 ± 80	202 ± 105	252 ± 121
SO_2 PPM	29 ± 6	27 ± 5	28 ± 6	28 ± 5
THC PPM	19 ± 37	13 ± 17	11 ± 23	14 ± 27
Combustion Efficiency %	99.693	99.794	99.812	99.765
THC Peaks/h > 600 PPM	1.41	0	0	0.47
THC Peaks/h > 300 PPM	4.94	0.71	0	0.94
CO Peaks/h > 1500 PPM	0.71	2.12	0.71	1.18
FLUE GAS VOLUME m^3/h	157,000	158,000	N/A	158,000
FLUE GAS VOLUME Nm^3/h	53,800	55,400	N/A	54,700
FLUE GAS MOISTURE (H_2O) %	18.4	15.	N/A	16.7
OPACITY %	11.3 ± 1.6	9.9 ± 1.3	10.8 ± 1.5	10.7 ± 1.5
OPACITY PEAKS/h > 20 %	2.12	1.42	0	1.18

SWARU COMBUSTION STUDY
DIAGNOSTIC TEST DATA PART 1

May 10, 1983
Run: 10-1

Steam Flow	kg/s	8.46
Overfire Air Distribution		
Upper Back		Open
Lower Back		Open
Upper Front		Closed
Lower Front		Closed
Size Distribution by Weight of Air Dry Fuel		
Oversize	%	5.64
>50.8 mm	%	10.53
<50.8 >12.7 mm	%	35.47
<12.7 mm	%	48.37
Fuel Air Dry Moisture	%	24.05 ± 9.38
Total Air	%	201
Bottom Ash	g/s	565
Particulate Carryover	g/s	133
Combustibles	%	8.4
Precipitator Ash	g/s	190
Stack Concentration		
Particulate	mg/Nm^{3*}	578
Dioxin	ug/Nm^{3*}	3.1
Furan	ug/Nm^{3*}	9.2
Chlorobenzenes	ug/Nm^{3*}	81.6
PCB's	ug/Nm^{3*}	304.9
Chlorophenols	ug/Nm^{3*}	51.2

* Trace organic concentrations corrected to 12% CO_2.

SWARU COMBUSTION STUDY
DIAGNOSTIC TEST DATA PART 2

May 10, 1983

RUN NO.	10-1/T1	10-1/T2	10-1/T3	10-1/AVE
START TIME	11:00	13:40	17:00	11:00
FINISH TIME	12:38	15:05	18:25	18:25
GRATE CONDITIONS	HEAVY PILING	LITTLE PILING	MODERATE PILING	
STEAM FLOW kg/s	8.44 ± .77	8.32 ± .77	8.59 ± .65	8.46 ± .71
AIR FLOW (% of Comb Air Supplied)				
UNDERGRATE	71	70	71	71
OVERFIRE AIR	29	30	29	29
CHUTE INFILTRATION AIR	24	22	23	23
AIR HEATER EXIT GAS	142	141	142	142
GRATE TEMPERATURE C	233 ± 12	244 ± 13	248 ± 12	242 ± 14
LOWER FURNACE TEMPERATURE C	737 ± 153	746 ± 88	798 ± 75	767 ± 113
UPPER FURNACE TEMPERATURE C	613 ± 124	642 ± 117	662 ± 127	641 ± 125
TOP TEMPERATURE C	641 ± 49	643 ± 31	670 ± 41	653 ± 44
AIR HEATER EXIT GAS TEMP C	361 ± N/A	376 ± 31	380 ± 42	372 ± 30
DRY FLUE GAS ANALYSIS				
O_2 %	10.3 ± 1.7	10.8 ± 1.52	10.4 ± 1.5	10.4 ± 1.5
CO_2 %	10.3 ± 1.5	10.2 ± 1.2	10.3 ± 1.2	10.3 ± 1.2
CO PPM	437 ± 264	246 ± 141	127 ± 79	275 ± 201
SO_2 PPM	35 ± 10	37 ± 8	40 ± 9	37 ± 8
THC PPM	10 ± 26	16 ± 11	26 ± 17	17 ± 20
Combustion Efficiency %	99.575	99.754	99.877	99.733
THC Peaks/h 600 PPM	0	0	0.71	0.16
THC Peaks/h 300 PPM	1.22	0.71	0.71	0.90
CO Peaks/h 1500 PPM	1.22	0.71	0.71	0.90
FLUE GAS VOLUME m^3/h	142,000	136,000	144,000	141,000
FLUE GAS VOLUME Nm^3/h	53,900	52,500	53,300	53,200
FLUE GAS MOISTURE (H_2O) %	12.9	15.3	14.5	14.2
OPACITY %	10.5 ± .9	11.1 ± 1.3	11.7 ± .7	11.1 ± 1.1
OPACITY PEAKS/h 20 %	1.22	0	2.84	1.35

SWARU COMBUSTION STUDY
DIAGNOSTIC TEST DATA PART 1

May 11, 1983
Run: 11-1

Steam Flow		kg/s	8.65
Overfire Air Distribution			
	Upper Back		Half Open
	Lower Back		Half Open
	Upper Front		Closed
	Lower Front		Closed
Size Distribution by Weight of Air Dry Fuel			
	Oversize	%	11.13
	>50.8 mm	%	7.99
<50.8	>12.7 mm	%	33.89
	<12.7 mm	%	46.99
Fuel Air Dry Moisture		%	24.57 ± 5.53
Total Air		%	208
Bottom Ash		g/s	581
Particulate Carryover		g/s	132
Combustibles		%	7.6
Precipitator Ash		g/s	216
Stack Concentration			
	Particulate	mg/Nm^3*	421
	Dioxin	ug/Nm^3*	1.3
	Furan	ug/Nm^3*	3.9
	Chlorobenzenes	ug/Nm^3*	34.8
	PCB's	ug/Nm^3*	97.0
	Chlorophenols	ug/Nm^3*	44.5

* Trace organic concentrations corrected to 12% CO_2.

SWARU COMBUSTION STUDY
DIAGNOSTIC TEST DATA PART 2

May 11, 1983

RUN NO.	11-1/T1	11-1/T2	11-1/T3	11-1/AVE
START TIME	11:10	13:25	15:55	11:10
FINISH TIME	12:35	14:50	17:20	17:20
GRATE CONDITIONS	LITTLE PILING	LITTLE PILING	MODERATE PILING	
STEAM FLOW kg/s	8.60 ± .85	8.57 ± .86	8.70 ± .78	8.65 ± .81
AIR FLOW (% of Comb Air Supplied)				
UNDERGRATE	72	72	73	73
OVERFIRE AIR	28	28	27	27
CHUTE INFILTRATION AIR	24	27	30	27
AIR HEATER EXIT GAS	140	144	139	141
GRATE TEMPERATURE C	239 ± 10	244 ± 11	242 ± 10	242 ± 11
LOWER FURNACE TEMPERATURE C	747 ± 87	743 ± 134	808 ± 155	764 ± 130
UPPER FURNACE TEMPERATURE C	638 ± 112	641 ± 111	647 ± 109	642 ± 111
TOP TEMPERATURE C	651 ± 29	648 ± 34	648 ± 37	649 ± 33
AIR HEATER EXIT GAS TEMP C	373 ± 24	375 ± 31	378 ± 38	376 ± 31
DRY FLUE GAS ANALYSIS				
O_2 %	11.0 ± 1.3	11.3 ± 1.3	10.5 ± 1.4	11.0 ± 1.4
CO_2 %	9.8 ± 1.2	9.5 ± 1.2	10.2 ± 1.2	9.8 ± 1.2
CO PPM	370 ± 190	262 ± 193	300 ± 190	308 ± 190
SO_2 PPM	39 ± 101	52 ± 13	49 ± 12	47 ± 13
THC PPM	6 ± 21	12 ± 23	17 ± 32	12 ± 26
Combustion Efficiency %	99.622	99.725	99.705	99.687
THC Peaks/h 600 PPM	0	0.71	0	0.24
THC Peaks/h 300 PPM	0	0.71	0	0.24
CO Peaks/h 1500 PPM	0	1.41	0	0.47
FLUE GAS VOLUME m^3/h	162,000	162,000	162,000	162,000
FLUE GAS VOLUME Nm^3/h	60,300	59,000	60,000	59,800
FLUE GAS MOISTURE (H_2O) %	15.6	16.4	14.9	15.6
OPACITY %	12.0 ± 1.2	11.3 ± 1.4	12.2 ± 1.9	11.8 ± 1.5
OPACITY PEAKS/h 20 %	2.12	2.13	1.41	1.92

SWARU COMBUSTION STUDY
DIAGNOSTIC TEST DATA PART 1

May 12, 1983
Run: 12-1

Steam Flow	kg/s	8.43
Overfire Air Distribution		
Upper Back		Closed
Lower Back		Closed
Upper Front		Closed
Lower Front		Closed
Size Distribution by Weight of Air Dry Fuel		
Oversize	%	10.48
>50.8 mm	%	9.54
<50.8 >12.7 mm	%	40.93
<12.7 mm	%	39.06
Fuel Air Dry Moisture	%	26.28 ± 9.47
Total Air	%	224
Bottom Ash	g/s	537
Particulate Carryover	g/s	195
Combustibles	%	7.6
Precipitator Ash	g/s	281
Stack Concentration		
Particulate	mg/Nm^{3*}	796
Dioxin	ug/Nm^{3*}	1.7
Furan	ug/Nm^{3*}	6.0
Chlorobenzenes	ug/Nm^{3*}	63.8
PCB's	ug/Nm^{3*}	244.5
Chlorophenols	ug/Nm^{3*}	101.0

* Trace organic concentrations corrected to 12% CO_2.

SWARU COMBUSTION STUDY
DIAGNOSTIC TEST DATA PART 2

May 12, 1983

RUN NO.	12-1/T1	12-1/T2	12-1/T3	12-1/AVE
START TIME	12:00	14:25	16:30	12:00
FINISH TIME	13:25	15:45	17:55	17:55
GRATE CONDITIONS	LITTLE PILING	NO PILING	LITTLE PILING	
STEAM FLOW kg/s	8.38 ± 1.00	8.43 ± .85	8.48 ± .78	8.43 ± .85
AIR FLOW (% of Comb Air Supplied)				
UNDERGRATE	78	78	79	78
OVERFIRE AIR	22	22	21	22
CHUTE INFILTRATION AIR	33	41	41	39
AIR HEATER EXIT GAS	N/A	142	140	140
GRATE TEMPERATURE C	233 ± 5	229 ± 5	229 ± 7	231 ± 6
LOWER FURNACE TEMPERATURE C	798 ± 92	775 ± 86	819 ± 142	791 ± 109
UPPER FURNACE TEMPERATURE C	662 ± 116	638 ± 110	663 ± 108	654 ± 111
TOP TEMPERATURE C	654 ± 39	633 ± 43	660 ± 48	649 ± 43
AIR HEATER EXIT GAS TEMP C	386 ± 29	376 ± 19	391 ± 52	384 ± 35
DRY FLUE GAS ANALYSIS				
O_2 %	10.9 ± 1.4	12.1 ± 1.5	12.1 ± 1.4	11.7 ± 1.5
CO_2 %	9.8 ± 1.2	8.8 ± 1.1	8.6 ± 1.1	9.1 ± 1.3
CO PPM	302 ± 182	338 ± 215	508 ± 646	378 ± 382
SO_2 PPM	54 ± 12	45 ± 11	29 ± 14	43 ± 16
THC PPM	18 ± 28	11 ± 16	47 ± 148	24 ± 84
Combustion Efficiency %	99.692	99.614	99.408	99.583
THC Peaks/h > 600 PPM	1.41	0	1.41	0.96
THC Peaks/h > 300 PPM	1.41	0.75	2.12	1.44
CO Peaks/h > 1500 PPM	1.41	2.25	1.41	1.68
FLUE GAS VOLUME m^3/h	165,000	168,000	169,000	167,000
FLUE GAS VOLUME Nm^3/h	58,300	61,500	64,600	61,500
FLUE GAS MOISTURE (H_2O) %	16.3	15.5	12.3	14.7
OPACITY %	12.9 ± 1.3	12.5 ± 1.2	14.0 ± 1.3	13.1 ± 1.4
OPACITY PEAKS/h > 20 %	4.94	3.75	9.87	6.24

SWARU COMBUSTION STUDY
DIAGNOSTIC TEST DATA PART 1

May 13, 1983
Run: 13-1

Steam Flow	kg/s	5.15
Overfire Air Distribution		
Upper Back		Closed
Lower Back		Closed
Upper Front		Closed
Lower Front		Closed
Size Distribution by Weight of Air Dry Fuel		
Oversize	%	6.16
>50.8 mm	%	9.08
<50.8 >12.7 mm	%	28.32
<12.7 mm	%	56.44
Fuel Air Dry Moisture	%	29.30 ± 5.71
Total Air	%	433
Bottom Ash	g/s	437
Particulate Carryover	g/s	192
Combustibles	%	7.7
Precipitator Ash	g/s	154
Stack Concentration		
Particulate	mg/Nm^{3*}	383
Dioxin	ug/Nm^{3*}	3.8
Furan	ug/Nm^{3*}	7.3
Chlorobenzenes	ug/Nm^{3*}	47.1
PCB's	ug/Nm^{3*}	210.6
Chlorophenols	ug/Nm^{3*}	158.3

* Trace organic concentrations corrected to 12% CO_2.

SWARU COMBUSTION STUDY
DIAGNOSTIC TEST DATA PART 2

May 13, 1983

RUN NO.	13-1/T1	13-1/T2	13-1/T3	13-1/AVE
START TIME	10:35	12:50	15:15	10:35
FINISH TIME	12:00	14:15	16:40	16:40
GRATE CONDITIONS	NO PILING	NO PILING	NO PILING	
STEAM FLOW kg/s	4.74 ± .87	5.66 ± .37	5.04 ± .76	5.15 ± .78
AIR FLOW (% of Comb Air Supplied)				
UNDERGRATE	76	76	76	76
OVERFIRE AIR	24	24	24	24
CHUTE INFILTRATION AIR	30	34	30	31
AIR HEATER EXIT GAS	140	N/A	147	143
GRATE TEMPERATURE C	201 ± 5	210 ± 6	209 ± 6	207 ± 7
LOWER FURNACE TEMPERATURE C	648 ± 82	685 ± 93	622 ± 80	659 ± 91
UPPER FURNACE TEMPERATURE C	528 ± 86	562 ± 86	522 ± 85	543 ± 87
TOP TEMPERATURE C	554 ± 71	586 ± 34	564 ± 67	572 ± 55
AIR HEATER EXIT GAS TEMP C	318 ± 23	329 ± 19	319 ± 23	322 ± 22
DRY FLUE GAS ANALYSIS				
O_2 %	15.6 ± 1.3	15.3 ± 1.1	15.9 ± 1.0	15.6 ± 1.1
CO_2 %	5.2 ± 1.1	5.5 ± 1.1	5.0 ± 1.0	5.2 ± .8
CO PPM	1052 ± 1648	616 ± 453	871 ± 557	846 ± 574
SO_2 PPM	6 ± 1	16 ± 4	16 ± 2	13 ± 5
THC PPM	182 ± 114	103 ± 115	187 ± 160	157 ± 134
Combustion Efficiency %	97.969	98.874	98.240	98.373
THC Peaks/h > 600 PPM	0.71	2.82	4.24	2.59
THC Peaks/h > 300 PPM	3.53	6.35	7.06	5.65
CO Peaks/h > 1500 PPM	7.06	4.94	4.94	5.65
FLUE GAS VOLUME m^3/h	131,000	139,000	169,000	146,000
FLUE GAS VOLUME Nm^3/h	54,400	57,900	67,600	60,000
FLUE GAS MOISTURE (H_2O) %	13.5	11.0	14.6	13.0
OPACITY %	12.0 ± 1.3	12.3 ± 1.0	12.7 ± 2.4	12.6 ± 1.6
OPACITY PEAKS/h > 20 %	2.13	1.41	.71	1.41

SWARU COMBUSTION STUDY
DIAGNOSTIC TEST DATA PART 1

May 17, 1983
Run: 17-1

Steam Flow	kg/s	8.32
Overfire Air Distribution		
Upper Back		Half Open
Lower Back		Half Open
Upper Front		Closed
Lower Front		Closed

Size Distribution by Weight of Air Dry Fuel		
Oversize	%	4.08
>50.8 mm	%	9.58
<50.8 >12.7 mm	%	36.18
<12.7 mm	%	50.16
Fuel Air Dry Moisture	%	30.08 ± 2.30

Total Air	%	198
Bottom Ash	g/s	605
Particulate Carryover	g/s	222
Combustibles	%	7.6
Precipitator Ash	g/s	230

Stack Concentration		
Particulate	mg/Nm^3*	384
Dioxin	ug/Nm^3*	1.4
Furan	ug/Nm^3*	5.4
Chlorobenzenes	ug/Nm^3*	53.3
PCB's	ug/Nm^3*	2315.7
Chlorophenols	ug/Nm^3*	36.1

* Trace organic concentrations corrected to 12% CO_2.

SWARU COMBUSTION STUDY
DIAGNOSTIC TEST DATA PART 2

May 17, 1983

RUN NO.	17-1/T1	17-1/T2	17-1/T3	17-1/AVE
START TIME	11:25	14:30	19:40	11:25
FINISH TIME	13:15	16:30	21:25	21:25
GRATE CONDITIONS	HEAVY PILING	HEAVY PILING	HEAVY PILING	
STEAM FLOW kg/s	8.44 ± 1.05	8.29 ± 1.36	8.18 ± .82	8.32 ± 1.08
AIR FLOW (% of Comb Air Supplied)				
UNDERGRATE	71	70	72	71
OVERFIRE	29	30	28	29
CHUTE INFILTRATION AIR	N/A	32	32	32
AIR HEATER EXIT GAS	148	158	158	155
GRATE TEMPERATURE C	246 ± 9	249 ± 11	238 ± 11	244 ± 12
LOWER FURNACE TEMPERATURE C	754 ± 84	739 ± 107	716 ± 99	737 ± 98
UPPER FURNACE TEMPERATURE C	746 ± 191	742 ± 192	736 ± 212	741 ± 198
TOP TEMPERATURE C	678 ± 54	673 ± 49	657 ± 50	669 ± 51
AIR HEATER EXIT GAS TEMP C	364 ± 30	364 ± 33	359 ± 19	362 ± 27
DRY FLUE GAS ANALYSIS				
O_2 %	10.7 ± 2.5	10.4 ± 2.1	11.3 ± 1.8	10.8 ± 2.1
CO_2 %	9.8 ± 2.1	10.2 ± 1.9	9.3 ± 1.5	9.8 ± 1.9
CO PPM	425 ± 352	470 ± 545	451 ± 317	449 ± 409
SO_2 PPM	58 ± 22	56 ± 19	57 ± 19	57 ± 19
THC PPM	253 ± 619	290 ± 648	38 ± 43	195 ± 523
Combustion Efficiency %	99.565	99.538	99.517	99.540
THC Peaks/h > 600 PPM	3.0	2.82	0	1.96
THC Peaks/h > 300 PPM	5.25	4.94	0	3.43
CO Peaks/h > 1500 PPM	4.5	3.53	N/A	4.00
FLUE GAS VOLUME m^3/h	145,000	153,000	139,000	146,000
FLUE GAS VOLUME Nm^3/h	54,700	54,700	50,100	53,200
FLUE GAS MOISTURE (H_2O) %	13.6	16.4	20.2	16.8
OPACITY %	12.4 ± 1.4	13.7 ± 2.1	10.9 ± 1.2	12.4 ± 2.0
OPACITY PEAKS/h > 20 %	6.75	7.76	.75	5.14

SWARU COMBUSTION STUDY
DIAGNOSTIC TEST DATA PART 1

May 19, 1983
Run: 19-1

Steam Flow	kg/s	5.48
Overfire Air Distribution		
Upper Back		Closed
Lower Back		Closed
Upper Front		Closed
Lower Front		Closed
Size Distribution by Weight of Air Dry Fuel		
Oversize	%	6.25
>50.8 mm	%	6.71
<50.8 >12.7 mm	%	30.25
<12.7 mm	%	56.32
Fuel Air Dry Moisture	%	30.92 $\pm$ 3.51
Total Air	%	406
Bottom Ash	g/s	629
Particulate Carryover	g/s	179
Combustibles	%	5.9
Precipitator Ash	g/s	192
Stack Concentration		
Particulate	mg/Nm^3*	110
Dioxin	ug/Nm^3*	5.0
Furan	ug/Nm^3*	9.4
Chlorobenzenes	ug/Nm^3*	69.0
PCB's	ug/Nm^3*	1218.1
Chlorophenols	ug/Nm^3*	192.9

* Trace organic concentrations corrected to 12% CO_2.

SWARU COMBUSTION STUDY
DIAGNOSTIC TEST DATA PART 2

May 19, 1983

RUN NO.	19-1/T1	19-1/T2	19-1/T3	19-1/AVE
START TIME	10:40	13:00	15:05	10:40
FINISH TIME	12:05	14:20	16:30	16:30
GRATE CONDITIONS	HEAVY PILING	MODERATE PILING	LITTLE PILING	
STEAM FLOW kg/s	6.28 ± .30	5.37 ± .96	4.78 ± .72	5.48 ± .93
AIR FLOW (% of Comb Air Supplied)				
UNDERGRATE	75	74	75	75
OVERFIRE	25	26	25	25
CHUTE INFILTRATION AIR	31	31	32	31
AIR HEATER EXIT GAS	152	150	141	149
GRATE TEMPERATURE C	214 ± 6	212 ± 7	203 ± 7	210 ± 8
LOWER FURNACE TEMPERATURE C	654 ± 150	611 ± 110	578 ± 82	613 ± 120
UPPER FURNACE TEMPERATURE C	659 ± 188	639 ± 200	611 ± 187	636 ± 192
TOP TEMPERATURE C	608 ± 45	584 ± 78	568 ± 46	587 ± 59
AIR HEATER EXIT GAS TEMP C	336 ± 32	320 ± 34	311 ± 19	323 ± 30
DRY FLUE GAS ANALYSIS				
O_2 %	15.4 ± 1.0	15.6 ± 1.6	15.3 ± 1.0	15.5 ± 1.2
CO_2 %	5.4 ± .9	5.5 ± 1.4	5.7 ± 1.0	5.5 ± 1.1
CO PPM	822 ± 396	1037 ± 692	1193 ± 639	1017 ± 595
SO_2 PPM	30 ± 6	26 ± 8	36 ± 9	31 ± 9
THC PPM	164 ± 125	232 ± 148	320 ± 175	239 ± 162
Combustion Efficiency %	98.489	98.108	97.896	98.161
THC Peaks/h > 600 PPM	3.53	7.5	11.29	7.44
THC Peaks/h > 300 PPM	8.47	9	19.05	12.24
CO Peaks/h > 1500 PPM	4.94	9.75	13.41	9.36
FLUE GAS VOLUME M^3/h	135,000	137,000	134,000	135,000
FLUE GAS VOLUME Nm^3/h	53,700	57,900	60,300	57,300
FLUE GAS MOISTURE (H_2O) %	13.7	10.9	9.9	11.5
OPACITY %	12.1 ± 1.0	10.6 ± 1.5	9.4 ± 9	10.7 ± 1.6
OPACITY PEAKS/h > 20 %	.71	.75	.71	.72

SWARU COMBUSTION STUDY
DIAGNOSTIC TEST DATA PART 1

May 24, 1983
Run: 24-1

Steam Flow	kg/s	8.23
Overfire Air Distribution		
Upper Back		Closed
Lower Back		Closed
Upper Front		Closed
Lower Front		Closed
Size Distribution by Weight of Air Dry Fuel		
Oversize	%	21.49
>50.8 mm	%	10.00
< 50.8 >12.7 mm	%	30.80
<12.7 mm	%	37.72
Fuel Air Dry Moisture	%	32.12 ± 4.76
Total Air	%	263
Bottom Ash	g/s	589
Particulate Carryover	g/s	170
Combustibles	%	11.5
Precipitator Ash	g/s	339
Stack Concentration		
Particulate	mg/Nm^{3*}	739
Dioxin	ug/Nm^{3*}	1.7
Furan	ug/Nm^{3*}	7.3
Chlorobenzenes	ug/Nm^{3*}	152.3
PCB's	ug/Nm^{3*}	1390.2
Chlorophenols	ug/Nm^{3*}	152.3

* Trace organic concentrations corrected to 12% CO_2.

SWARU COMBUSTION STUDY
DIAGNOSTIC TEST DATA PART 2

May 24, 1983

RUN NO.	24-1/T1	24-1/T2	24-1/T3	24-1/AVE
START TIME	10:55	14:55	19:40	10:55
FINISH TIME	12:20	16:15	21:16	21:16
GRATE CONDITIONS	HEAVY PILING	MODERATE PILING	HEAVY PILING	
STEAM FLOW kg/s	8.03 ± 1.4	8.34 ± .47	8.19 ± .81	8.23 ± .93
AIR FLOW (% of Comb Air Supplied)				
UNDERGRATE	77	78	77	77
OVERFIRE	23	22	23	23
CHUTE INFILTRATION AIR	29	28	28	28
AIR HEATER EXIT GAS	132	138	133	134
GRATE TEMPERATURE C	238 ± 7	241 ± 7	244 ± 6	241 ± 7
LOWER FURNACE TEMPERATURE C	738 ± 158	715 ± 111	714 ± 114	723 ± 131
UPPER FURNACE TEMPERATURE C	612 ± 96	615 ± 141	618 ± 153	615 ± 128
TOP TEMPERATURE C	657 ± 55	676 ± 35	675 ± 43	669 ± 46
AIR HEATER EXIT GAS TEMP C	367 ± 99	379 ± 34	374 ± 45	373 ± 64
DRY FLUE GAS ANALYSIS				
O_2 %	13.9 ± 1.3	13.5 ± 0.8	13.7 ± 1.2	13.5 ± 1.2
CO_2 %	7.0 ± 1.3	7.2 ± 0.8	7.8 ± .9	7.4 ± 1.1
CO PPM	644 ± 392	373 ± 172	466 ± 333	495 ± 325
SO_2 PPM	29 ± 8	39 ± 8	43 ± 10	38 ± 11
THC PPM	41 ± 212	83 ± 114	174 ± 365	137 ± 263
Combustion Efficiency %	99.084	99.481	99.406	99.330
THC Peaks/h > 600 PPM	9.18	2.25	5.58	5.74
THC Peaks/h > 300 PPM	15.53	4.50	6.98	9.08
CO Peaks/h > 1500 PPM	4.94	0.75	4.19	3.35
FLUE GAS VOLUME m^3/h	147,000	150,000	147,000	148,000
FLUE GAS VOLUME Nm^3/h	56,100	53,200	53,600	54,300
FLUE GAS MOISTURE (H_2O) %	11.6	18.1	15.6	15.1
OPACITY %	9.2 ± 10.5	14.8 ± .5	13.9 ± 1.8	15.8 ± 6.2
OPACITY PEAKS/h > 20 %	12.00	14.25	3.49	9.81

SWARU COMBUSTION STUDY
DIAGNOSTIC TEST DATA PART 1

May 25, 1983
Run: 25-1

Steam Flow	kg/s	8.79
Overfire Air Distribution		
Upper Back		Open
Lower Back		Open
Upper Front		Closed
Lower Front		Open
Size Distribution by Weight of Air Dry Fuel		
Oversize	%	8.49
>50.8 mm	%	8.15
<50.8 >12.7 mm	%	37.20
<12.7 mm	%	46.17
Fuel Air Dry Moisture	%	31.97 ± 5.43
Total Air	%	294
Bottom Ash	g/s	688
Particulate Carryover	g/s	215**
Combustibles	%	9.1
Precipitator Ash	g/s	220
Stack Concentration		
Particulate	mg/Nm^3*	286
Dioxin	ug/Nm^3*	11.1
Furan	ug/Nm^3*	12.5
Chlorobenzenes	ug/Nm^3*	65.7
PCB's	ug/Nm^3*	537.6
Chlorophenols	ug/Nm^3*	7.4

* Trace organic concentrations corrected to 12% CO_2.
** Based on two traverses only.

SWARU COMBUSTION STUDY
DIAGNOSTIC TEST DATA PART 2

May 25, 1983

RUN NO.	25-1/T1	25-1/T2	25-1/AVE
START TIME	12:30	15:20	12:30
FINISH TIME	13:55	16:30	16:33
GRATE CONDITIONS	MODERATE PILING	MODERATE PILING	
STEAM FLOW kg/s	8.61 ± 1.24	9.01 ± 1.18	8.79 ± 1.20
AIR FLOW (% of Comb Air Supplied)			
UNDERGRATE	68	68	68
OVERFIRE	32	32	32
CHUTE INFILTRATION	34	32	33
AIR HEATER EXIT GAS	139	137	138
GRATE TEMPERATURE C	263 ± 9	265 ± 10	264 ± 9
LOWER FURNACE TEMPERATURE C	751 ± 82	786 ± 157	766 ± 122
UPPER FURNACE TEMPERATURE C	640 ± 112	691 ± 148	663 ± 132
TOP TEMPERATURE C	663 ± 21	677 ± 52	670 ± 38
AIR HEATER EXIT GAS TEMP C	401 ± 53	391 ± 65	397 ± 58
DRY FLUE GAS ANALYSIS			
O_2 %	13.2 ± 0.6	14.3 ± 1.8	13.7 ± 1.4
CO_2 %	7.5 ± 0.5	6.7 ± 1.7	7.1 ± 1.2
CO PPM	158 ± 81	600 ± 938	358 ± 621
SO_2 PPM	70 ± 12	40 ± 12	57 ± 20
THC PPM	56 ± 138	279 ± 651	157 ± 456
Combustion Efficiency %	99.790	99.103	99.499
THC Peaks/h > 600 PPM	4.24	9.43	6.58
THC Peaks/h > 300 PPM	4.24	10.29	6.97
CO Peaks/h > 1500 PPM	2.82	5.14	3.87
FLUE GAS VOLUME m^3/h	156,000	158,000	157,000
FLUE GAS VOLUME Nm^3/h	57,100	55,200	56,200
FLUE GAS MOISTURE (H_2O) %	14.2	17.4	15.8
OPACITY %	15.7 ± 2.8	17.8 ± 1.9	16.7 ± 60
OPACITY PEAKS/h > 20 %	8.48	18.86	9.29

SWARU COMBUSTION STUDY
DIAGNOSTIC TEST DATA PART 1

May 26, 1983
Run: 26-1

Steam Flow	kg/s	5.01
Overfire Air Distribution		
Upper Back		Closed
Lower Back		Open
Upper Front		Closed
Lower Front		Closed
Size Distribution by Weight of Air Dry Fuel		
Oversize	%	7.69
>50.8 mm	%	12.47
<50.8 >12.7 mm	%	35.03
<12.7 mm	%	44.82
Fuel Air Dry Moisture	%	31.79 $\pm$ 3.95
Total Air	%	369
Bottom Ash	g/s	519
Particulate Carryover	g/s	90
Combustibles	%	6.8
Precipitator Ash	g/s	78
Stack Concentration		
Particulate	mg/Nm^{3*}	170
Dioxin	ug/Nm^{3*}	5.8
Furan	ug/Nm^{3*}	8.9
Chlorobenzenes	ug/Nm^{3*}	49.0
PCB's	ug/Nm^{3*}	1279.9
Chlorophenols	ug/Nm^{3*}	160.1

* Trace organic concentrationis corrected to 12% CO_2.

SWARU COMBUSTION STUDY
DIAGNOSTIC TEST DATA PART 2

May 26, 1983

RUN NO.	26-1/T1	26-1/T2	26-1/T3	26-1/AVE
START TIME	11:10	14:25	16:50	11:10
FINISH TIME	12:35	15:50	18:40	18:40
GRATE CONDITIONS	MODERATE PILING	LITTLE PILING	HEAVY PILING	
STEAM FLOW kg/s	5.03 ± .30	4.57 ± .79	5.34 ± .63	5.01 ± .67
AIR FLOW (% of Comb Air Supplied)				
UNDERGRATE	65	65	64	65
OVERFIRE	35	35	36	35
CHUTE INFILTRATION	28	35	34	32
AIR HEATER EXIT GAS	156	154	156	155
GRATE TEMPERATURE C	241 ± 17	247 ± 19	252 ± 21	247 ± 19
LOWER FURNACE TEMPERATURE C	546 ± 84	508 ± 58	587 ± 88	547 ± 85
UPPER FURNACE TEMPERATURE C	654 ± 246	589 ± 174	611 ± 169	618 ± 200
TOP TEMPERATURE C	541 ± 32	536 ± 24	582 ± 32	554 ± 36
AIR HEATER EXIT GAS TEMP C	306 ± 22	305 ± 17	326 ± 19	312 ± 22
DRY FLUE GAS ANALYSIS				
O_2 %	15.2 ± 1.4	16.6 ± 1.4	13.5 ± 1.4	15.1 ± 1.9
CO_2 %	5.9 ± 1.4	4.4 ± 1.3	7.3 ± 1.2	5.9 ± 1.7
CO PPM	626 ± 324	502 ± 357	380 ± 146	500 ± 294
SO_2 PPM	35 ± 10	22 ± 11	39 ± 9	32 ± 12
THC PPM	69 ± 47	37 ± 26	89 ± 217	65 ± 131
Combustion Efficiency %	98.941	98.856	99.477	99.138
THC Peaks/h > 600 PPM	0	0	0.63	0.23
THC Peaks/h > 300 PPM	0	1.41	1.89	1.13
CO Peaks/h > 1500 PPM	0.71	1.41	1.89	1.36
FLUE GAS VOLUME m^3/h	121,000	98,400	110.000	110.000
FLUE GAS VOLUME Nm^3/h	53,500	44,300	44,700	47,500
FLUE GAS MOISTURE (H_2O)%	7.2	7.4	11.8	8.80
OPACITY %	11.1 ± 1.0	11.5 ± 1.7	11.4 ± 1.1	11.3 ± 1.2
OPACITY PEAKS/h > 20 %	0	0	0	0